MECHANICAL STOKERS

Interior View of a Modern Boiler Plant Equipped with Mechanical Stokers. *Frontispiece.*

MECHANICAL STOKERS

INCLUDING THE

THEORY OF COMBUSTION OF COAL

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PREFACE

There are few, if any, books on Mechanical Stokers, which are available for young engineers to study in preparation for combustion or stoker work. Many books have been published on boilers, furnaces and power plant equipment treated as a whole, but none treating stokers as separate units. Nor have any of these outlined the best modern practice in stoker installation and use.

There seems to be a demand for such a book; treating on combustion as it applies specifically to stoker work, with something definite about mechanical stokers and their applications, as well as the factors affecting their selection for differing conditions and widely differing fuels.

This book is presented to fill this need. It is a record of first-hand knowledge of combustion and stoker work gained in years of theoretical and practical experience. The endeavor throughout is to give reliable unbiased opinions and facts from actual field experience in the design, installation and operation of stokers.

The Authors feel that there are great possibilities in a book of this character; something which will cover the entire stoker industry. With this thought in mind, constructive criticism and suggestions are invited, to the end that new ideas may be incorporated when a revision is found necessary.

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MECHANICAL STOKERS

CHAPTER I

PRINCIPLES OF COMBUSTION

A knowledge of some of the fundamental principles of chemistry is necessary for the engineer who deals with combustion problems. These principles when considered in connection with mechanical stokers are confined to the burning of various grades of coal, lignite and coke. The chemistry of some of the steps in the combustion of these fuels is quite complicated, especially when considering the volatile contents, but a thorough knowledge of this phase of the combustion process is not necessary for an understanding of the engineer's problems.

A working knowledge of gas analysis apparatus and especially a chemist's appreciation of the necessity for care and accuracy, with the ability to make the necessary calculations and draw correct conclusions from the results, is all the engineer requires.

The principal elements encountered in combustion problems are, carbon, hydrogen, oxygen, nitrogen, and sulphur.

Carbon.—Carbon is found in solid fuels in two forms. In the solid state it is known as fixed carbon because it remains unchanged when the fuel is heated to a temperature sufficient to drive off the moisture and volatile contents. In combination with hydrogen it forms the combustible volatile, and also occurs in small quantities in combination with oxygen.

Hydrogen.—Hydrogen is found in fuels in combination with both carbon and oxygen. The hydrogen-carbon or hydro-carbon content is an important part of solid fuels both with regard

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to heating value and to the manner in which the fuel will burn. The caking of certain fuels during the early stages of the combustion process is due to the action of certain hydro-carbon compounds which act as a binder to cement the particles together into large masses. The hydrogen in combination with oxygen makes up the moisture content of the fuel and has little or no effect upon its characteristics.

Oxygen.—Oxygen which forms 20.91% of air by volume, and 23.15% by weight, is always available in unlimited quantities to support combustion. When present in the fuel itself, it serves no useful purpose as it has already combined with either carbon or hydrogen and is therefore not active in the combustion process.

Nitrogen.—Nitrogen is an inert element brought into the combustion process by the oxygen with which it is mixed in the air. It acts as a diluent, reducing the activity of the oxygen and greatly affecting the temperature of combustion. The heating of the large amount of nitrogen contained in the air used for combustion is the chief cause of heat loss in the burning of fuel, since it escapes at very much higher temperatures than it enters the furnace.

Sulphur.—Sulphur is found in all solid fuels and is responsible for much of the trouble encountered in furnaces. When present in small amounts its effect is negligible but fuels containing four or five per cent sulphur are often difficult to burn. While the sulphur itself is a combustible element and unites readily with oxygen, it has the effect of lowering the fusing temperature of ash and causing the formation of clinkers. This is especially true when it is present in the form of iron pryities. When present in the form of sulphate of lime, it has no heating value.

Air.—Pure dry air contains 209.1% oxygen and 79.09% nitrogen by volume and 23.15% oxygen and 76.85% nitrogen by weight. The air supplied for combustion contains in addition a very small percentage of CO_2 and a quantity of water which depends upon the relative humidity and the temperature. Their effect on the combustion process is so slight, however, that both are usually disregarded in all except the most refined computations.

Air supplied for Combustion.—When a given weight of fuel is burned, a definite amount of heat is available for such work as generating steam. The heat evolved raises the temperature of the resultant gases and this rise in temperature will depend upon the weight of gas to be heated and its specific heat. It is apparent that if a large excess of air be supplied, the temperature will be lower than if only the theoretical amount were used, and since the escaping gas temperature is always above that of the air originally supplied, the loss increases as the amount of excess air is increased. The weight of air supplied for combustion, to a large extent, determines the efficiency of the process, and is the most important factor in the efficient operation of furnaces.

The weight of air supplied may be determined from an analysis of the furnace gases and since the analysis is most conveniently made by volume, the formulae by which the weight may be determined directly from the analysis by volume of the gases, are most convenient. When pure carbon is burned in dry air the products of combustion are carbon dioxide, carbon monoxide, oxygen and nitrogen. The sum of the carbon dioxide, carbon monoxide, oxygen and nitrogen represents the entire weight of gaseous products and the dry gas per pound of carbon may be expressed as the relation of the total dry products of combustion to the total weight of carbon in the flue gases. This carbon may be present both as CO_2 and CO. Carbon represents 3/11 of the total weight of CO_2 and 3/7 of the total weight of CO. This relation may, therefore, be expressed:

Dry gas per lb. of carbon =

$$\frac{100}{\frac{3}{11}CO_2+\frac{3}{7}CO} \quad \text{or} \quad \frac{CO_2+CO+O_2+N_2}{\frac{3}{11}CO_2+\frac{3}{7}CO}.$$

In order to reduce this expression to a form in which percentages by volume may be used, each term must be multiplied by its relative density (see table 1). The equation therefore becomes:

$$\text{Dry gas per lb. of carbon} = \frac{11CO_2+8O_2+7[CO+N_2]}{3(CO_2+CO)}.$$

TABLE No. 1

AIR REQUIRED FOR COMBUSTION

Fuel	Reaction	Pounds O per Pound, Fuel	Pounds Air per Pound, Fuel	Weight Total Gaseous Products per Pound, Fuel	Relative Density	Heat Liberated B.T.U. per Pound, Fuel
C	$C+2O = CO_2$	2.67	11.52	12.52	22	14,540
C	$C+O = CO$	1.34	5.76	6.76	14	4,380
CO	$CO+O = CO_2$	0.57	2.47	3.47	22	10,150
H	$2H+O = H_2O$	8.0	34.56	35.56	9	62,000
S	$S+2O = SO_2$	1.0	4.32	5.32	32	4,050

This equation is correct for the burning of pure carbon in dry air but in actual practice several other factors must be considered. The sulphur content of fuel introduces a slight error in the above equation and a correction should be made for fuels high in sulphur. The CO_2 resulting from the burning of one pound of carbon is 3.67 lbs. and the weight of SO_2 from one lb. of sulphur is 2 lbs. 1 lb. of carbon in the fuel therefore accounts for the same weight of products of combustion as would result from the burning of 1.83 lbs. of sulphur. In using the above formula, the sulphur content can be corrected for by adding to the total weight of carbon burned, the total weight of sulphur divided by 1.83 and the equation for determining the total weight of the dry products of combustion will be

Formula No. 1.

$$\text{Dry gas per lb. of fuel} = \frac{11CO_2+8\,O_2+7(CO+N_2)}{3(CO_2+CO)}\ C+\frac{S}{1.83},$$

where C and S are the percentages by weight of carbon and sulphur contained in the fuel.

One lb. of hydrogen unites with 8 lbs. of oxygen which is provided by supplying 34.56 lbs. of dry air, the products of

combustion being 9 lbs. of superheated steam and 26.56 lbs. of nitrogen and the total weight will be

$$\frac{(35.56\times \text{per cent hydrogen in fuel})}{100}.$$

The nitrogen appears in the flue gas analysis but the superheated steam is condensed in the gas analysis apparatus. The oxygen required to burn hydrogen therefore does not appear in the analysis while the nitrogen is present and the result is an increase in the percentage of nitrogen and a decrease in the sum of the percentages of carbon dioxide, carbon monoxide and oxygen. Fuels containing hydrogen when burned with the theoretical weight of air will give a smaller percentage of CO_2 in the gas than those containing no hydrogen. Pure carbon burned with the theoretical air supply would give products of combustion containing 20.91% carbon dioxide. With natural gas the percentage of CO_2 in the flue gas when the theoretical amount of air is supplied may be as low as 11.5%. It is therefore apparent that the percentage of excess air cannot be determined from the gas analysis without an analysis of the fuel burned. When a number of calculations of excess air from gas analyses are to be made it is most convenient to prepare a table or curve showing the relation between CO_2 and excess air for a fuel of the given analysis.

The following calculations will show the method of preparing such a table:

Assume the following coal analysis:

Carbon	72.60
Hydrogen	4.50
Oyxgen	4.25
Nitrogen	1.75
Sulphur	1.50
Ash	15.40
	100.00

For perfect combustion the air required and the resultant products of combustion will be:

	Weight per Pound of Coal, Pounds	Required for Combustion per Pound of Coal, Pounds		Products of Combustion, Pounds per Pound of Coal				
		O_2	Air	CO_2	O_2	N_2	H_2O	SO_2
C	.7260	1.936	8.364	2.662	....	6.428		
H_2	.0450	.360	1.555	....	....	1.195	.405	
O_2	.0425	.....	.....	....	.043			
N_2	.0175	.....	.....	....	....	.018		
S	.0150	.015	.065	....	....	.050	....	.030
Ash	.1540							
	1.0000	2.311	9.984	2.662	.043	7.691	.405	.030

A correction must be made in the oxygen and air required for combustion, due to the presence of oxygen in the original fuel. This also affects the weight of nitrogen as calculated above. A second correction is necessary because the sulphur dioxide is absorbed in the gas analysis apparatus along with the carbon dioxide. The corrected quantities will be:

	Required for Combustion per Pound of Coal,		Products of Combustion, Pounds per Pound of Coal				
	O_2	Air	CO_2	O_2	N_2	H_2O	SO_2
	2.311	9.984	2.662	.043	7.691	.405	.030
Correction for O_2 in coal	−.043	−.186	....	−.043	−.143		
	2.268	9.798	2.662	.000	7.548	.405	.030
Correction for SO_2 absorbed as CO_2	......	......	+.030	....	....	....	−.030
	2.268	9.798	2.692	.000	7.548	.405	.000

The weight of air required is 9.798 lbs. per lb. of coal and the products of combustion will weigh 10.645 lbs. If 10%

excess air be supplied there will be an increase of .98 lb. in the products of combustion, .754 lb. of which will be nitrogen and .226 lb. oxygen. The weight in lbs. of the products of combustion for varying amounts of excess air will be:

WEIGHT OF PRODUCTS OF COMBUSTION. POUNDS PER POUND OF COAL

	Per Cent Excess Air								
	0	10	20	30	40	50	60	80	100
CO_2	2.692	2.692	2.692	2.692	2.692	2.692	2.692	2.692	2.692
O_2	.000	.226	.452	.678	.904	1.130	1.356	1.808	2.260
N_2	7.548	8.302	9.056	9.810	10.564	11.318	12.072	13.580	15.088
H_2O	.405	.405	.405	.405	.405	.405	.405	.405	.405
Total....	10.645	11.625	12.605	13.585	14.565	15.545	16.525	18.485	20.445
Total dry products	10.240	11.220	12.200	13.180	14.160	15.140	16.120	18.080	20.040

The weight of CO_2, O_2 and N_2 expressed as percentages of the total dry products will be:

	Per Cent Excess Air								
	0	10	20	30	40	50	60	80	100
CO_2	26.29	23.99	22.05	20.42	19.01	17.78	16.70	14.88	13.43
O_2	.00	2.01	3.71	5.14	6.38	7.46	8.41	10.00	11.28
N_2	73.71	74.00	74.24	74.44	74.61	74.76	74.89	75.12	75.29

Gas analyses are usually given in terms of volume and it is therefore preferable to convert the above results into percentages by volume. This is done by dividing the percentage by weight of each constituent by its relative density and then dividing each value thus obtained by the sum of the values.

PER CENT VOLUME OF DRY PRODUCTS

	Per Cent Excess Air								
	0	10	20	30	40	50	60	80	100
CO_2	18.50	16.77	15.34	14.14	13.11	12.22	11.44	10.14	9.13
O_2	.00	1.93	3.54	4.88	6.05	7.04	7.93	9.38	10.53
N_2	81.50	81.30	81.12	80.98	80.84	80.74	80.63	80.48	80.34

In the use of gas analysis apparatus, particular care should be taken to secure an average sample. In boiler furnaces it is difficult if not impossible to secure an average sample before the gas enters the heating surface of the boiler, because the gases rising from different parts of the fuel bed are not of uniform analysis. The mixing effect of contact with the tubes and changes in direction of gas travel caused by the boiler baffles is such that an average sample can be secured in the last pass of the boiler but samples taken at points nearer the furnace are always of questionable value.

Temperature of Combustion.—The function of a boiler furnace is to heat gas. The boiler then cools this gas, transmitting the heat to the steam and water. Since the extent to which the cooling process can be carried is limited on account of the temperature of the water in the boiler, it follows that for best results, the gas should leave the furnace as hot as possible and every factor affecting the temperature attainable should be carefully considered.

The temperature of the products of combustion depends upon the heat units produced, the weight of the products of combustion and the mean specific heat between the initial and final temperatures of the air and fuel. Since the specific heat will vary over a range of temperature it is impossible to make a direct calculation of combustion temperatures. A value must be assumed for the mean specific heat based on an assumed temperature of combustion and a trial calculation made. If this calculation shows a temperature different from the assumed temperature, a new value for the specific heat must be taken, assuming a maximum temperature between the first assumed

value and the calculated value. The second calculation will be more accurate than the first and this process may be repeated until the desired degree of accuracy is secured.

In actual practice, three factors affect the maximum temperature as follows: first, it is impossible to secure complete combustion without an excess over the theoretical amount of air required, and the temperature decreases with the increase in the amount of excess air supplied; second, an excess of air being required for complete combustion, it is evident that if this excess be reduced too far, incomplete combustion results, and the full amount of heat in the fuel is not liberated; third, radiation from the burning fuel carries away heat. In the case of a boiler furnace where a part of the heating surface is in proximity to the fuel bed, a large amount of heat is absorbed by direct radiation and the temperature is thereby reduced.

Since the quantity of heat radiated from the burning fuel is a function of the time as well as the temperature, it follows that the lower the rate of combustion, the greater is the percentage of heat carried away by radiation. The rate of combustion, therefore, affects the temperature of the fire, the temperature increasing as the combustion rate increases, provided of course, the relation of fuel to air is maintained constant.

Temperature of the Furnace.—The temperature of a boiler furnace is affected by a number of factors and varies in different parts of the furnace. The burning fuel is at one temperature, but this temperature varies for different stages of combustion, the gases leaving the fuel bed are at a different temperature, and the furnace brick work at a still different temperature. The heating surface of the boiler which is in proximity to the furnace being only a few degrees hotter than the water in the boiler, has a decided cooling effect upon the furnace and prevents the other parts of the furnace from reaching the temperatures that would otherwise result. It is apparent that the temperature may be increased by moving the boiler surface farther from the furnace and interposing a roof of refractory material. The design of the furnace, therefore, has an important effect on the temperature and no accurate knowledge of the amount of excess air present can be secured

from furnace temperature alone. Temperatures of over 3000° F. may be secured in furnaces burning coal at high rates of combustion and admitting not more than 30% excess air, but such temperatures are seldom attained in actual practice except for short intervals, and rapid burning of furnace brick work would result if such temperatures were maintained for long periods of time. In actual practice, the temperatures vary from 2400° to 3000° when furnaces are operated economically and are carrying fair overloads, and will go as low as 1500° F. at low ratings, and with inefficient operation.

Efficiency of Combustion.—While the burning of fuel in a furnace and the utilization of the heat thus liberated for the generation of steam, are two separate and distinct processes, they are so closely related, that the factors affecting efficiency are most conveniently considered for the furnace and boiler taken as a unit.

The complete list of losses is as follows:

1. Heat carried away in the dry chimney gases.
2. Unburned gases discharged with the products of combustion.
3. Superheated steam formed by burning hydrogen in the fuel and by evaporating the moisture in the coal.
4. Superheating the moisture in the air.
5. Combustible discharged to the ash pit.
6. Sensible heat in the ash pit refuse.
7. Soot and cinders deposited in the gas passages and carried away with the chimney gases.
8. Radiation.

Fine particles of fuel which sift through the grates are sometimes improperly included with the losses. This is a deliberate waste and has no place in the list of losses, because the siftings are easily reclaimed and should be returned to the furnace.

Heat Carried Away by the Dry Chimney Gases.—The fuel and air used for combustion are supplied at atmospheric temperature and the heat necessary to raise this temperature to that of the escaping gases is lost, the amount of the loss depending upon the rise of temperature and the weight of gas.

The weight of gas is calculated from formula No. 1, (Page 4) when the weight of C burned per pound of coal as fired is known. This can be determined from an analysis of the fuel

and ash with an allowance for the weight of carbon carried away by the escaping gases or deposited in gas passages.

If $C_b = \%$ C burned per lb. of coal as fired, corrected for sulphur content; $C_b = \%$ C in actual coal$+\left(\frac{S}{1.83}\right)-[(\%$ C carried away by gases$+\%$ C rejected to the ash pit]. (The % C lost in the ash pit being determined by subtracting the % ash in the coal from the % of dry refuse in the pit.)

Let T_f = temperature of the escaping gases in degrees F.,

T_a = temperature of the air in degrees F.

Specific heat of dry gas = .24.

Then heat carried away by dry chimney gases per lb. of

$$\text{Coal} = \left(C_b \frac{(11\ CO_2 + 8O + 7\ (CO + N))}{3\ (CO + CO_2)}\right) \times .24(T_f - T_a)\Big).$$

If great accuracy is desired a calculation of the average specific heat between T_f and T_a should be made and the actual value used instead of .24. For ordinary calculations, however, .24 is sufficiently accurate.

Loss due to Unburned Gases Discharged with the Products of Combustion.—In determining the loss due to incomplete combustion, it is assumed that the hydrogen has all been burned and that the incomplete combustion is represented entirely by CO in the escaping gases. The equation for determining this loss may be derived as follows:

The loss due to incomplete combustion is determined as follows:

$$\text{C in } CO = \tfrac{3}{7}\ CO;$$
$$\text{C in } CO_2 = \tfrac{3}{11}\ CO_2;$$
$$\text{C in gas} = \tfrac{3}{7}\ CO + \tfrac{3}{11}\ CO_2;$$
$$\frac{\tfrac{3}{7}\ CO}{\tfrac{3}{7}\ CO + \tfrac{3}{11}\ CO_2} = \text{proportional part of C remaining in the form of CO.}$$

Multiplying each member by its relative density, this expression reduces to $\left(\frac{CO}{CO + CO_2}\right)$ = pounds of C in CO per pound of C burned.

The combustion of 1 pound of C contained in CO to CO_2 generates 10,150 B.T.U.

The loss due to CO per pound $C = \left(\frac{CO}{CO+CO_2}\right) \times 10{,}150.$

Loss per pound of coal as fired $= \left(\frac{CO}{CO+CO_2}\right) \times 10{,}150 \times C_b.$

This expression is correct if the only unburned fuel in the furnace gases is present in the form of CO. It is known, however, that this is not correct although the extent and nature of the unconsumed hydro-carbons is not fully understood.

When coal is heated to a temperature of 500° F., distillation of the volatile content begins and both gaseous and liquid hydro-carbons are liberated. The rate of liberation increases until the temperature reaches about 1000° F. after which there is a gradual decrease.

These hydro-carbons are very complex in their structure and no accurate information is available as to the exact steps in their complete combustion. It is probable, however, that the hydro-carbons are distilled from the coal in the form of liquid tar and tar vapors which undergo chemical changes when brought into the region of high temperature with a certain amount of free oxygen present, and there is every indication that some of the combustible gases evolved are discharged unburned when an attempt is made to reduce the excess air too far or where the furnace is not of sufficient size to allow time for the completion of the combustion process. A careful analysis of boiler tests which have been conducted with the utmost care shows that the unaccounted for loss is greater in those cases where the furnace is small than where furnaces of liberal proportions are used. Since the unaccounted for loss could not be accounted for in any other way, it is apparent that in the smaller furnaces there is a certain loss due to incomplete combustion of the hydro-carbons, which is not detected by the gas analysis and which is not necessarily accompanied by the production of smoke. A similar condition exists when comparing tests run at different ratings on the same furnace. At the higher ratings the unaccounted for loss increases in spite of the fact that the radiation which is an important factor in the unaccounted for loss is a smaller percentage than at the

lower ratings. The increase in unaccounted for loss is therefore evidently due to some form of incomplete combustion which is not detected in the ordinary gas analysis instrument.

Loss Due to Superheated Steam Formed by Burning Hydrogen in the Fuel and by Evaporating the Moisture.—For each unit weight of hydrogen in the fuel, nine times this weight of superheated steam results from burning the hydrogen.

The moisture in the fuel is also evaporated and escapes as superheated steam. The resultant loss may be determined as follows:

$H_2O = \%$ moisture in coal as fired;
$H = \%$ H in coal as fired;
.50 in specific heat of superheated steam.

$$\text{Loss due to } H_2O \text{ in coal} = \frac{H_2O}{100}\left[(212 - T_a) + 970.4 + .50\ (T_f - 212)\right]$$

$$\text{Loss due to H in coal} = \frac{9\ H}{100}\left[(212 - T_a) + 970.4 + .50\ (T_f - 212)\right].$$

These losses may be expressed in one equation:

$$\frac{(H_2O + 9\ H)}{100}\left[(212 - T_a) + 970.4 + .50\ (T_f - 212)\right].$$

While hydrogen in fuel adds materially to its heating value, it also increases the necessary loss due to the escape of superheated steam and thereby lowers the efficiency. Other factors being equal, a fuel with low hydrogen content would be desirable from the standpoint of most efficient combustion.

In spite of the fact that the moisture content is also responsible for a loss of heat, many fuels can be more satisfactorily burned by the addition of from 3% to 5% surface moisture. This is not due to any chemical action of the moisture but to its effect on the nature of the fuel bed. This matter will be referred to in detail later.

Combustible Discharged at the Ash Pit.—The heat loss due to the presence of combustible in the ash pit is usually over estimated. A comparatively small percentage of unburned carbon is plainly visible and may appear to represent a much

larger loss than actually exists. The loss per pound of coal as fired may be calculated from the following formula:

$$h = H\,\frac{(\%\ \text{refuse} \times \%\ \text{C in refuse})}{100},$$

in which H = calorific value of carbon and h = heat loss per pound of coal as fired.

Sensible Heat in the Ash Pit Refuse.—The hot ash and refuse carry a certain amount of sensible heat away from the furnace. The specific heat of the refuse is about .28 and the loss from this source would be represented by the following equation:

$$\frac{T_a \times .28 \times \%\ \text{refuse per lb. of coal}}{100}.$$

The temperature at which the refuse is discharged varies considerably with different methods of firing but in most cases, averages from 1500° to 2000° F.

Soot and Cinders Deposited in the Gas Passages or Carried Away by the Chimney Gases.—In a well designed and properly operated furnace, the fuel loss due to soot accumulations is negligible.

With poor design and improper operation, dense clouds of black smoke may be discharged and a small amount of carbon in the form of soot is thus lost but it is doubtful if this loss ever reaches 1% of the fuel. The large loss of which dense smoke is the visible sign, is not due to the particles of soot discharged but to the incomplete combustion of the hydrocarbons.

It is well known that a rapidly moving current of air or gas will carry in suspension particles heavier than air, especially if they are small. In this manner cinders are carried over into the boiler passes and breeching and are deposited at points where there is a sudden change in the direction of flow or a reduction in velocity due to increased crossed section of the gas passage. The lighter particles being held in suspension the longest, are discharged to the atmosphere with the chimney gases.

The loss due to cinders may be as high as 2% of the total coal fired, especially when furnaces are operated at high capacities and gases are traveling at high velocity.

Radiation and Miscellaneous.—The radiation from furnace and boiler brickwork depends very largely upon the construction of the furnace walls. At one time it was believed that this loss could be materially reduced by leaving an air space in the center of the walls but it has been found by careful experiments that the radiation across this air space actually increased the loss, and that filling the air spaces with sand or cinders resulted in a substantial decrease.

The temperature of a furnace wall will not increase in direct proportion to the rate of burning fuel and since the area of radiating surface is constant, the per cent of the total heat which is lost by radiation thereby decreases as the rating is increased.

When a boiler is banked the amount of fuel required to keep it in a standard condition is sometimes referred to as radiation loss, but this is not correct for the reason that under such conditions the fuel required to maintain the banked condition is burned very inefficiently and only a small part of the heat apparently generated is actually available.

The leakage of cold air through cracks in brickwork and through the brick itself is often a source of considerable loss, especially where the brickwork is unprotected and the boilers are operated with a high draft throughout the setting.

CHAPTER II

MECHANICAL STOKERS

From the time that coal was first fired on a grate, there seemed to be a pretty good understanding that the factors effecting the proper burning of coal were:

(a) A continuous feed of coal.
(b) Proper proportion of air and a mixture of air and gases.
(c) High temperatures.

It was, therefore, the ambition of most inventors in the early history of coal-burning devices, to conceive of some combination of things that would provide these conditions and thus lead to the burning of coal without smoke.

D. K. Clark, in his excellent treatise "The Steam Engine," gives some very interesting history of smoke contrivances that came from ambitious inventors in the early days—a review of some of the most important ones is interesting, as leading up to the mechanical feeding of fuel to furnaces.

SMOKE-PREVENTION CONTRIVANCES

Watt—1785 (*English*).—James Watt, the inventor of the steam engine, conceived the idea that the volatile gases of coal should be distilled slowly, and in one of his first furnaces (Fig. *1*), the coal was piled up at the front of the grate and then gradually pushed farther towards the rear, giving the volatile gases a chance to distill slowly. The coal piled up in front served to shut off excess air admittance to the furnace.

Robertson—1800 (*English*).—J. and J. Robertson thought it was necessary to admit air over the fire in order to completely burn the volatile gases. Their invention covered the admission of a sheet of air immediately over the coking part of the fuel

bed (Fig. *2*). It is interesting to note that this patent involves a coal hopper, a fuel-burning structure and a refuse disposal space; these are fundamental ideas and were later worked out

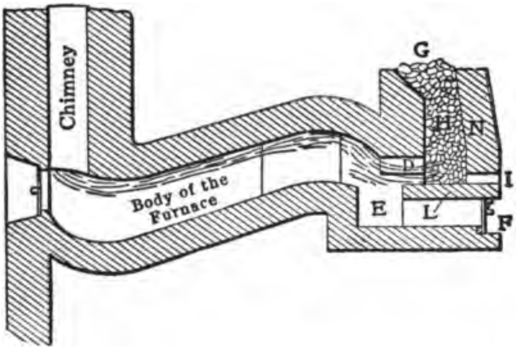


FIG. 1.—Watt's Smokeless Furnace.

and developed in connection with the design of mechanical stokers.

Wakefield—1810 (*English*).—John Wakefield had the same general idea that air was required over the fuel bed for smoke prevention and worked out the idea of passing air through a

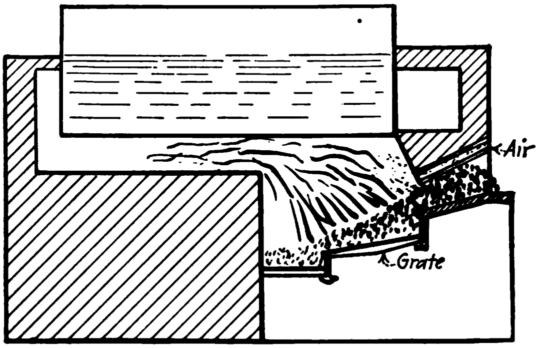


FIG. 2.—Robertson's System.

hollow bridgewall, thus heating the air before admitting it (Fig. *3*). This appears to be the first idea of admitting air over the fire at a point near the bridgewall.

Gregson—1816 (*English*)—Gregson, in 1816, used piers or bridges in a furnace, in order to obtain a mixture of the gases

(Fig. *4*). By the installation of two bridgewalls, the gases from the fuel bed were made to separate, part passing over the bridge and part underneath, and then coming in contact again with

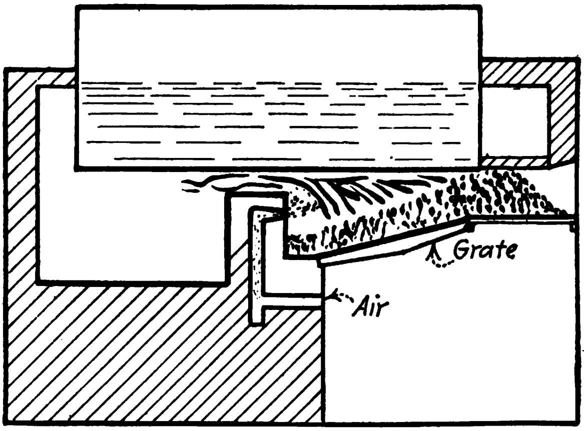


Fig. 3.—Wakefield's System.

an air admission before passing underneath the second bridge-wall.

This is probably the first idea of using bridges or piers for mixing and intermingling gases, and was used quite success-

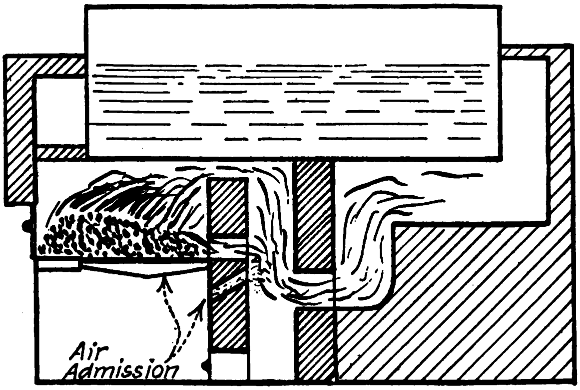


Fig. 4.—Gregson's System.

fully in later years in hand-fired furnaces for smoke prevention.

Witty—1828 (*English*).—R. Witty, it appears, had the first idea of using the gas-producer effect in burning coal. Coal was

admitted slowly, and a deep well provided in which the fuel was burned (Fig. 5). The volatile gases were made to pass upward over an incandescent fuel bed and, in this way, maintained high temperatures. It is said that this system failed on account of lack of air supply for the volatile gases.

Shanter—1834 (English).—John Shanter, following a similar idea of Gregson, used an inverted arch back of the bridgewall, and in combination with this, admitted air back of the bridgewall endeavoring to obtain a proper mixture of air and gases.

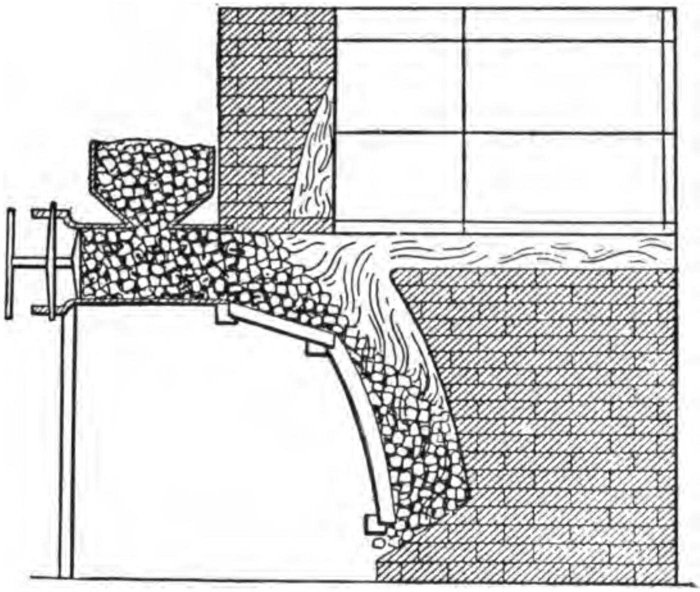


FIG. 5.—Witty's System of Furnace.

Gray and Shanter—1835 (English).—Gray & Shanter patented a system of two grates, one inclined for coking the coal, and the other for burning the fixed carbon. The coal, when the gases were distilled, was pushed back on the second grate. This is probably the fundamental idea of a down draft furnace that was used quite successfully in later years.

Rodda—1838 (English).—R. Rodda followed the same idea as Gregson, using an inverted arch in the center of the grate. In order to obtain a proper mixture, the air and gases were forced underneath this bridge.

Williams—1839 (*English*).—C. Wye Williams used an Argand blower to obtain a mixture of air and gases (Fig. 6). Air was introduced behind the bridgewall in finely divided streams, either by driving air through perforated pipes, or through perforated plates. In some of his patents, an ingenious idea for admitting air over the fire was obtained by taking out the center grate bars of a furnace and installing a perforated plate so that air could be admitted about 3 in. over the fire. This was very effective and streams of fire seemed to come from the orifices of this plate.

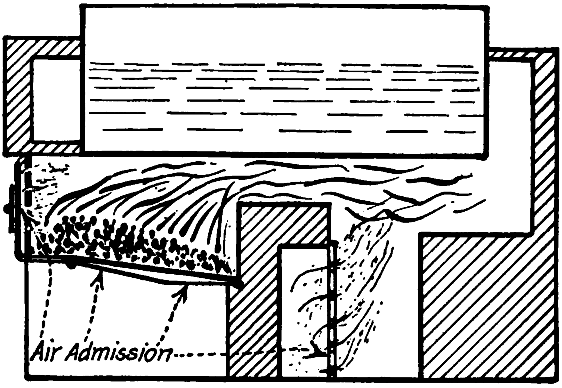


FIG. 6.—Williams' System.

Prideaux—1853 (*English*).—T. S. Prideaux is probably the first one who conceived the idea of automatically admitting air through the fire doors after each charge of fuel.

In the fire front, valves were used and controlled by hand levers, so that when opened, a full charge of air was admitted, and, by means of water cylinders, the system of valves and levers gradually fell and shut off the air.

Langen—1862 (*English*).—Langen developed the idea of an inclined stepped grate wherein the coal was pushed from one grate to another until completely burned (Fig. 7). This is a fundamental idea that probably led to the development of a stepped grate mechanical stoker.

Barber—1881 (*English*).—From the present knowledge of the requirements for burning coal without smoke, the early inventors were working under a serious handicap since all of

the contrivances were installed in connection with internally-fired boilers.

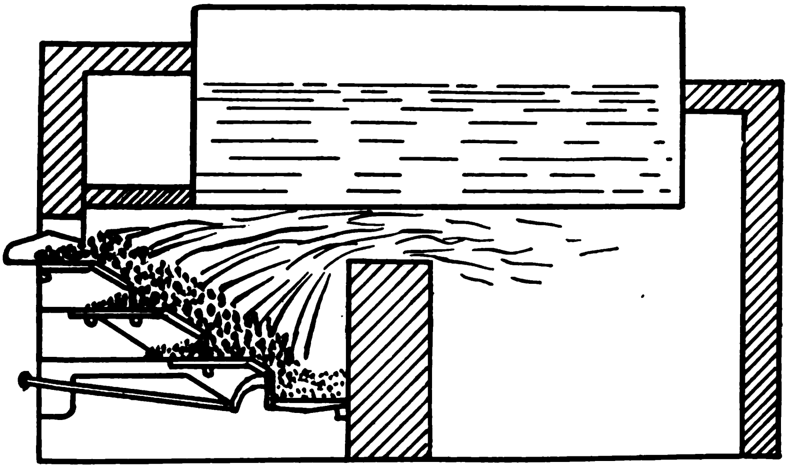


Fig. 7.—Langen's Stepped Grate.

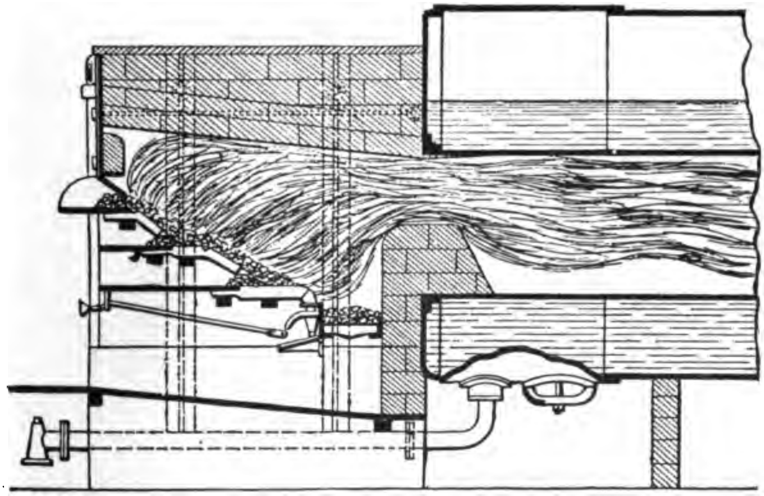


Fig. 8.—Barber's Stepped Furnace.

Barber's stepped furnace (Fig. 8), seems to be the first instance where an extended firebrick combustion chamber is used providing proper distance between the fuel bed and the

cool surfaces of the boiler. In all previous contrivances up to this time, the grate was placed very close to the cool surfaces of the boiler, and the gases had very little time in which to burn.

No doubt, this application feature was the reason for so many of the early contrivances failing insofar as smoke abatement was concerned.

MECHANICAL FEEDING OF COAL TO FURNACES

The many attempts to fire coal by hand, and to burn it without producing smoke led to an endeavor to mechanically produce the conditions necessary for proper combustion.

This development work seemed to be along the lines of producing these conditions by means of a traveling grate, an inclined grate or a screw conveyor. Thus, the fundamental principles of the present forms of traveling grate, overfeed and underfeed stokers, were established.

The principle of the traveling grate stoker is to deposit the fuel from suitable hoppers on a grate that moves slowly inward. The coal is first ignited and the volatiles driven off and progressing farther inward on the same grate, the fixed carbon is consumed. Air is admitted through the grates. At the end of the grate travel, at the rear of the furnace, the ash is dumped into a pit.

In the overfeed stokers, the coal from suitable hoppers is pushed in by mechanical means onto a coking plate where the volatile gases are distilled. The grate bars are inclined and given a movement and, aided by gravity, the fuel progresses over the grate and the fixed carbon is consumed. Air is admitted through the grates. The ash is collected at the bottom of the incline and there dumped into the ash pit periodically or crushed by ash grinders.

In the underfeed type of stoker, the coal is forced by mechanical means into a magazine or retort extending into the furnace. The coal is then pushed upwards into the incandescent fuel bed. Air under pressure is forced through the fuel bed. Ash is collected on plates at the side of the retorts or on dump grates at the rear of the furnace and periodically dropped into the ash pit.

TRAVELING GRATE STOKERS

Brunton—1819 (*English*).—The first mechanical stoker was brought out in England in 1819 by Wm. Brunton. This was a traveling grate stoker consisting of a circular grate revolving on a vertical spindle. The coal was fed to the grate from a suitable hopper, and as the grate gradually revolved, the volatile gases were distilled slowly, and finally the fixed carbon was consumed and ash and refuse pulled from the grate.

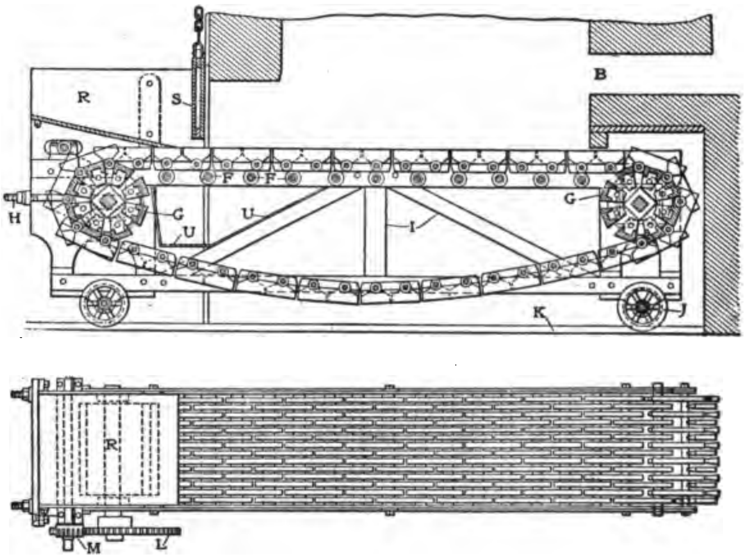


FIG. 9.—Jukes' Chain Grate Stoker of 1841.

Bodmer—1834 (*English*).—The first traveling grate that moved from the front of the boiler inward to the bridgewall was brought out by Bodmer in 1834. The grates moved slowly inward and were then dropped and returned to the front on rails or by means of screws. In the forward movement, the bars by setting in spiral screws were given a reciprocating movement, the aim being to break up the caking fuel bed.

Jukes—1841 (*English*).—The original traveling chain grate stoker was brought out in England by Jukes in 1841 (Fig. 9). The principle of this stoker was a number of longitudinal bars connected together to form an endless chain. This moved slowly

from the front of the furnace inward towards the rear, the coal being deposited on the grate from a suitable hopper and moving inward on the grate, the volatile gases were distilled slowly. The ash was dropped over the rear of the grate.

Weller—1871 (American).—The earliest record of a traveling grate stoker in America was that brought out by Royal F. Weller in 1871 (Fig. *10*). In this grate, the Jukes principle was used with the exception that the arrangement of the bars

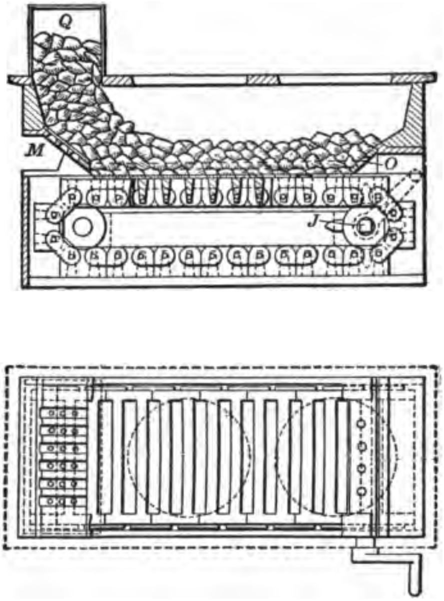


FIG. 10.—Weller Traveling Grate Stoker.

were made transversely instead of longitudinally. Each of the bars strung transversely across the furnace were fastened together by links and, in this way, an endless chain was made.

Coxe—1893 (American).—E. B. Coxe employed many novel features in a chain grate stoker, the most important of which were the method of air distribution and the design of the grates for burning small sizes of anthracite coals.

OVERFEED STOKER

Hall—1845 (English).—Probably the first attempt to mechanically feed a furnace fire by means of inclined grate bars was brought out by Hall in 1845 (Fig. *11*). Fuel was supplied from a hopper, in back of which channels were left for admitting air over the fire. The fuel was pushed onto inclined reciprocating grate bars. This original inclined overfeed stoker had the same general design principles as the present-day types, namely, a hopper for feeding fuel, an inclined grate for burning the fuel, and a sliding shelf for disposing of ash and refuse.

Vicars—1867 (English).—This development of the inclined grate stoker is interesting in that coal was fed onto grate bars

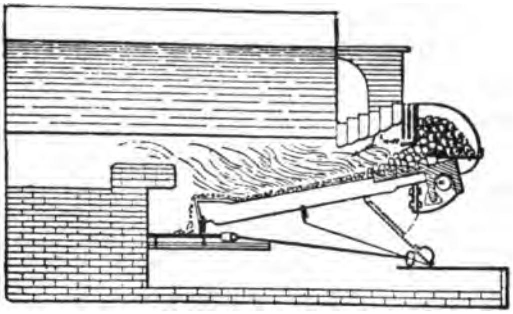


Fig. 11.—Samuel Hall's Smoke-preventing Apparatus.

by means of plungers (Fig. *12*), and the inclined grate bars were given a reciprocating motion to slowly advance the fuel. This stoker was used extensively in England.

McDougall—1880 (English).—This stoker covered the most complete combinations of the elements making up an inclined grate stoker. The coal was fed from suitable hoppers, being pushed onto a coking plate which projected somewhat into the furnace. Air was admitted over the fire at this point. The stroke of the rams feeding fuel into the furnace could be varied. The grate bars were given a reciprocating movement that gradually fed the fuel from the front of the stoker inwards. An arch was used for ignition purposes. Ash and refuse were collected on grates at the bottom of the furnace.

Murphy—1878 (American).—Thomas Murphy brought out a complete new design of an inclined grate stoker (Fig. *13*). This was probably the first American stoker that did not have some resemblance to former English patents. It, therefore, stands distinct as a combination of elements necessary for pro-

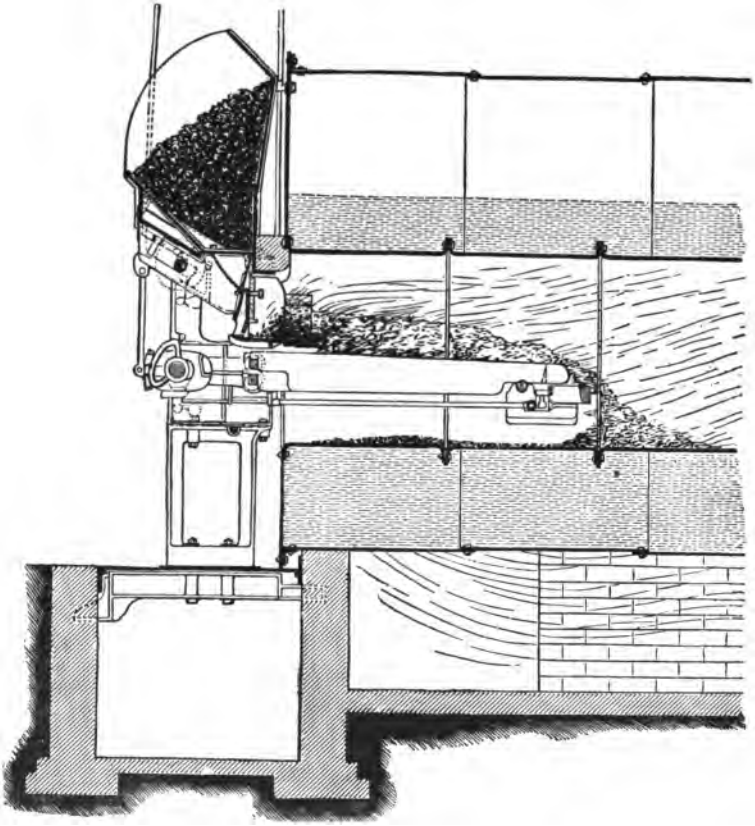


FIG. 12.—Vicar's Reciprocating Bar Stoker.

ducing conditions for proper combustion of coal. In this stoker, the fuel was fed onto grates from each side of the furnace, the grates being inclined towards the middle of the furnace so as to form a V-shaped cross section. A combustion arch was used extending across the grates above the end of the V. Arch channels were provided above the coking portion of the fuel bed for air admission for combustion of volatile gases. The grate bars

were given a reciprocating motion for breaking up the caking fuel bed. Ash and refuse were disposed of by means of a grinder located at the bottom of the V-shaped bars.

Roney—1885 (American).—Wm. R. Roney brought out a front inclined grate stoker which, although having the basic principles of some of the early English patents, was distinctive as to construction details (Fig. *14*). In this stoker, coal was fed from a hopper to a coking plate, and from there, by means of

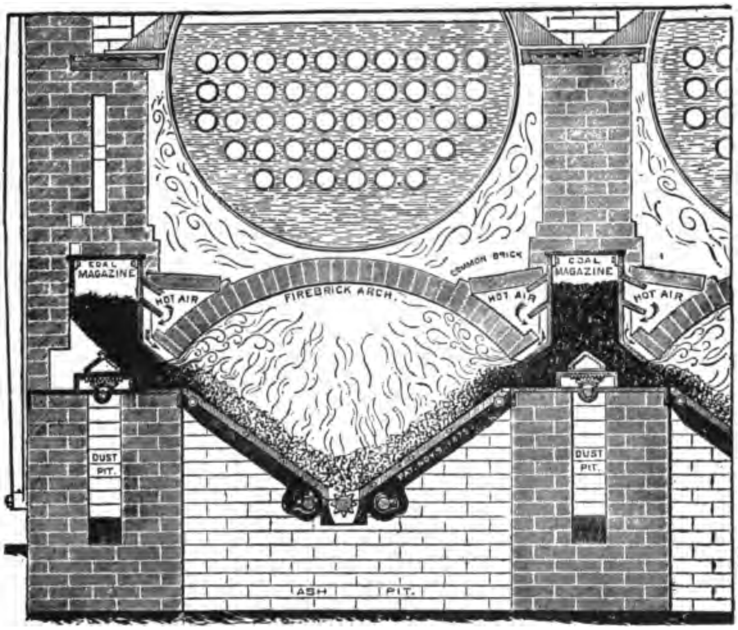


FIG. 13.—Murphy's Patent Smokeless Furnace.

gravity and rocking of the grate bars, the fuel bed progressed to the bottom of the furnace, depositing the ash on the dumping grates. At certain intervals, these dumping grates were dropped and the ash and refuse deposited in a pit.

Brightman—1885 (American).—About the same time that the Roney stoker was brought out, William Brightman patented a front inclined stoker which was distinctive as regards to the construction of the grate bars, but had the fundamental principles of the earlier forms of the inclined stoker.

Wilkinson—1890 (American).—Wilkinson brought out a distinctive, front inclined, stoker in that air was drawn in by steam jets, through hollow grate bars. It was designed particularly to burn small sizes anthracite coals. Coal was fed onto the grates by a pusher from a suitable hopper. The grate bars were inclined and given a reciprocating movement.

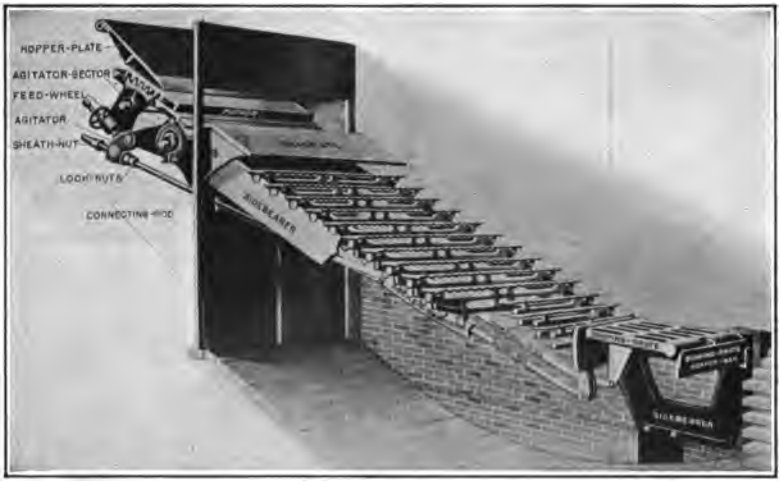


FIG. 14—William R. Roney's Original Stoker.

UNDERFEED STOKER

Holyrod-Smith (English).—The first English patent which brough forth the underfeed principle was that of Holyrod-Smith. The fuel was fed from a hopper into a horizontal trough lying across the front of the furnace. From this trough, the coal fell into three longitudinal troughs, placed at right angles and passing into the furnace. By certain construction of the screw conveyors in the troughs, the coal was lifted up into the burning fuel and onto perforated side castings through which air was admitted.

Jukes—1838 (English).—The same inventor of the traveling grate stoker also brought out a stoker involving the principle of underfeeding (Fig. *15*). Coal from a hopper dropped in front of a ram. A forward movement forced the coal into a retort and underneath the burning fuel. During this process, the volatile

gases were distilled, and the fixed carbon burned on fuel supporting grates.

Frisbie—1844 (*American*).—Following the underfeed principle, Frisbie patented an underfeed stoker in which fuel was

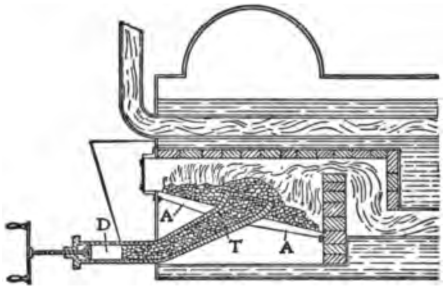


FIG. 15.—Jukes' Underfeed Stoker of 1838.

fed from beneath through a central aperture. The coal was fed into a hopper or box swinging on pivots. When the box was in place, a vertical movement of a plunger pushed the coal upward into the center of the fuel bed. When the box was

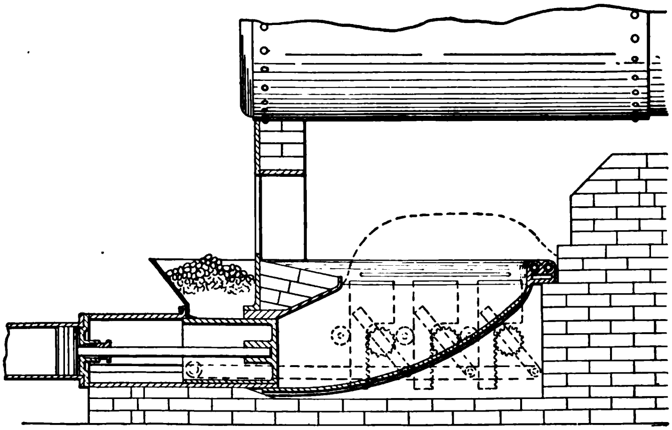


FIG. 16.—The First Coal-burning Jones' Underfeed Stoker.

empty and placed aside for refilling, a sliding plate closed the central aperture.

Jones—1889 (*American*).—Evan Jones brought out a successful underfeed stoker which, with development changes in details, is still being used successfully (Fig. *16*).

This stoker consisted of a hopper and plunger for feeding coal, and a retort extending into the furnace. Coal was forced forward, by means of the piston or ram, carrying a portion of the coal in the hopper to the furnace, and underneath the fuel bed. Air under pressure was forced into a sealed ash pit from there through tuyeres to the incandescent portion of the fuel bed.

Wood—1898 (*American*).—W. R. Wood brought out the American stoker. In principle, it was of the single retort type

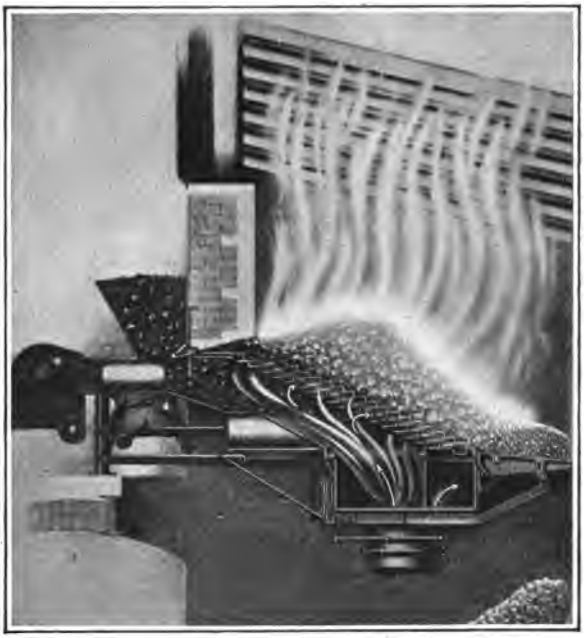


Fig. 17.—Early Form of the Taylor Underfeed Stoker.

but used a spiral screw for feeding coal from the hopper to the retort and forcing it up into the fuel bed.

Taylor—1903 (*American*).—Most of the early underfeed stoker inventions provided a single retort where the coal from the retort was distributed on dead plates and the ash and clinker pulled from the fire, through suitable doors in the front. Taylor brought out an underfeed stoker, which was distinct, in that a series of inclined retorts were used, being placed about 22 in. apart (Fig. *17*). Gravity was resorted to in the

progress of the fuel from the coal hopper to the refuse disposal plate at the bottom of the inclined retorts. Coal was forced into the furnace by plungers, and air admitted at pressure through tuyeres.

DEVELOPMENT OF MECHANICAL STOKERS

All of the early forms of mechanical stokers showed progress in mechanically burning fuel, but still there were many operating faults and, consequently, some skepticism as to the advisability of installing them. Many of the earlier forms of stokers were applied to internally-fired boilers, and there were many application problems. In the United States, the development of the steam engine, turbines and other prime movers naturally required an improvement in the character of firing coal in order to obtain better results. In the application of stokers, a proper conception of their scope, benefits and limitation must be known, but in the device itself there are five good reasons for their extended use and development, these being (1) To prevent smoke; (2) To conserve coal; (3) To produce conditions necessary for the most economical combustion of coal; (4) To save labor, and (5) To save equipment and investment.

(1) Smoke Prevention.—The factors effecting smoke prevention are:

(a) Continuous feed of coal.
(b) Volatile gases to be distilled slowly.
(c) Mixture of gases and air.
(d) Proper firebrick combustion chamber for maintaining proper temperature.

The mechanical stoker now does all of these things well and uniformly. It feeds the coal with mechanical regularity to a coking zone of the fuel bed. The volatile gases are distilled slowly. It is not necessary to feed coal to the fires by opening doors as in hand-firing, resulting in a reduction of furnace temperatures. The elimination of smoke by hand-firing depends too much on the human element. The character of manual labor that is now commercially available in boiler

rooms falls considerably short of the expertness required for smoke abatement when coal is fired by hand.

(2) Coal Conservation.—The principle of coal conservation is the transforming into useful work every pound of coal that is mined.

The mechanical stoker now does this better than hand-firing, With the proper stoker, a poorer and lower grade of fuel can be burned. Years ago, fine slack coal was without a market, because it could not be used successfully on a hand-fired grate. The stoker has been developed and now handles this coal successfully. Many plants in the United States today are using the richest coal (i. e., high in heat value, low in ash and sulphur), for industrial purposes on hand-fired grates, when low-grade coal should be used and the richest coal saved for other purposes where the poorer grade fuel cannot be used.

(3) Producing Conditions Necessary for the most Economical Combustion of Coal.—The factors effecting the proper burning of coal are:

(1) Fuel feed.
(2) Fuel burning.
  (a) Structure.
  (b) Air admission.
(3) Ash disposal.

The mechanical stoker has been developed to feed the fuel to the furnace by means of plungers or pushers with mechanical regularity. In this way, the volatile gases are distilled slowly, and there is sufficient time to admit the proper air for combustion. In a properly-designed stoker, the fuel bed has a progressive movement by means of traveling grates or movable grates, and it is not necessary to open doors to rake the fires. Air can be admitted at different zones of the fuel bed to burn the remaining combustibles.

The mechanical stoker meets load conditions better than hand-firing, for the reasons that the air admission can be adjusted to suit fuel bed conditions, and the rate of fuel feeding can be altered to meet rapid required changes in steam demands. In the stoker, the fires are either cleaned continuously or by dropping ash at the rear of the grates periodically.

(4) Labor Saving.—The factors effecting labor saving are:

(a) Installation of machinery.
(b) Intelligent supervision.

In any industry, labor is saved by the introduction of machinery. With the introduction of mechanical stokers, labor is saved just as soon as the requirements of the plant exceed the amount of coal that one man can fire by hand. The amount that labor can be reduced depends on the size of the plant.

A greater saving is made possible by the introduction of stokers, together with coal and ash-handling machinery. In one installation, twelve boilers were hand-fired by eight firemen and a water tender. With the installation of stokers, coal and ash-handling machinery, this was reduced to two men and a water tender.

The installation of mechanical stokers generally results in the use of a better class of labor in the boiler room, and consequently, a more intelligent supervision of that labor.

(5) Saving in Equipment and Investment.—The factors effecting a saving in boiler-room equipment are:

(a) Capacity of equipment.
(b) Flexibility of equipment.
(c) Economy of equipment.

With the introduction of modern mechanical stokers, coal can be burned at rates of 60 to 70 lbs. per sq. ft. of grate area per hour, and this can be done with little loss in efficiency. This is impractical with hand-firing which rarely exceeds 25 lbs. per sq. ft. per hour and means that with the installation of stokers, the number of boilers in a particular installation can be reduced when compared with a hand-fired installation.

In order to meet the sudden demands for steam, it is only necessary to increase the coal-burning rate of the stoker equipment already in service. With hand-firing which does not have this degree of flexibility, it is necessary to put additional boilers on the line, and this cannot be done in time to meet sudden demands for steam.

With modern stokers, boilers can be operated from 50% to 300% of boiler rating within a range of 15% efficiency. This flexibility is not obtained with hand-firing.

PRESENT TYPES OF MECHANICAL STOKERS IN THE UNITED STATES

The principal stokers now in use in the United States can be divided into the Chain Crate, Overfeed and Underfeed types. The names of the most prominent stokers are:

Traveling or Chain Grate

B. & W.	Manufactured by	Babcock & Wilcox Co.
Burke	" "	Burke Furnace Co.
Coxe	" "	Combustion Engineering Corp.
Green	" "	Green Engineering Co.
Harrington	" "	James A. Brady Foundry Co.
Illinois	" "	Illinois Stoker Co.
LaClede-Christy	" "	LaClede Christy Clay Prod. Co.
McKenzie	" "	McKenzie Furnace Co.
Playford	" "	Rosedale Foundry & Mach. Co.
Stowe	" "	LaClede Christy Clay Prod. Co.
Westinghouse	" "	Westinghouse Elec. & Mfg. Co.

Overfeed

Detroit	Manufactured by	Detroit Stoker Co.
Model	" "	Automatic Furnace Co.
Murphy	" "	Murphy Iron Works
Roney	" "	Westinghouse Elec. & Mfg. Co.
Wetzel	" "	Wetzel Stoker Co.

Underfeed (Multiple Retort)

Jones A. C.	Manufactured by	Underfeed Stoker Co. of America
Riley	" "	Sanford-Riley Stoker Co.
Taylor	" "	American Engineering Co.
Westinghouse	" "	Westinghouse Elec. & Mfg. Co.

Underfeed (Single Retort)

Jones	Manufactured by	Underfeed Stoker Co. of America.
Type "E"	" "	Combustion Engineering Corp.
Roach	" "	Roach Stoker Co.
Detroit	" "	Detroit Stoker Co.
Sturtevant	" "	B. F. Sturtevant Co.

CHAIN GRATE STOKERS

Babcock & Wilcox Chain Grate.—This stoker operates on natural draft. The chain (Fig. *18*) is made up of common and

driving links about 9 in. long with vertical air spaces. The links are spaced and held together by a steel rod passing through solid hubs. The chain passes over sprocket wheels at the front and rear of the grate, these being keyed to steel shafts. The shafts run in cast-iron bearings mounted in rectangular guides at the rear of the cast-iron side frames. Adjustment is provided by means of screws for both front and rear bearings. Such adjustment makes possible the taking up of sag in the chain.

The upper part of the chain is supported on rollers spaced 9 inches apart, and the lower portion on rollers spaced 18 inches

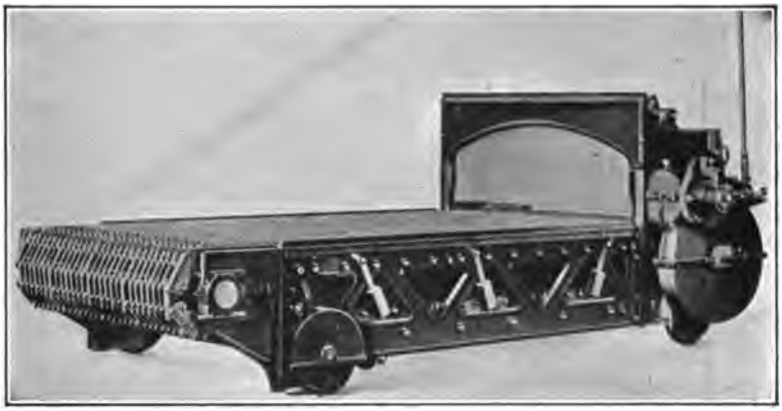


FIG. 18.—Babcock & Wilcox Chain Grate Stoker.

apart. These rollers are of wrought-iron pipe, to the ends of which cast-iron bushings are fitted. The bushings run on stationary wrought-steel axles extending from side to side on the grate and supported by the cast-iron frames.

The side frames are flush with the top of the grate. The inner sides of the flush portions form a guide against which the side links of the chain rub. At the outer edges of the side frames, side seals are provided for exclusion of air at the sides of the furnace. These seals are held by weighted levers against the under surface of cast-iron side plates which are built into the brickwork and overhang the side frames of the stoker.

The side frames are maintained at a proper distance from each other by means of steel spacing bolts front and rear, and

a cast-iron cross beam at the front, a wrought-steel channel at the front, a second wrought-steel channel between the chains at the front, and a third wrought-steel channel between the chains at the rear. Diagonal rods from side to side maintain the frames at right angles to the cross ties and shafts. The frame is mounted on four track wheels of cast iron, 18 inches in diameter, running on steel axles so that the stoker can be withdrawn from the furnace. The chain is about level from front to rear.

This last wrought-steel channel forms a part of the baffle at the rear of the stoker for excluding the air from this space. Below the channel a steel plate baffle forms an additional spacing piece. Hinged to the bottom of this stationary baffle plate a swinging steel plate, stiffened by angles, extends to the bottom of the ashpit between the stoker rails, completing the seal at the rear.

A coal hopper is formed at the front by the cast-iron hopper ends and by an inclined steel plate.

A coal gate, sliding vertically in removable guides bolted to the inner surface of the cast-iron hopper end pieces, furnishes a method of regulating the thickness of the fuel bed as fed to the forward end of the grate. The height of this gate is regulated by a hand wheel through a worm wheel and cross shaft, which raises or lowers the chains from which the gate is hung. The inner surface of this gate is lined with special shaped firebrick.

The front sprocket shaft is driven by a cast-iron worm wheel. This worm wheel engages a cast-iron worm secured to a worm shaft on the inner end of which is keyed one of a pair of mitre gears. Another mitre gear which engages this is actuated by a ratchet wheel. Long and short tool steel pawls drive this ratchet wheel from a cast-iron ratchet arm. A second pair of tool steel pawls prevents the ratchet wheel from moving backward.

The driving mechanism is encased with a cast-iron housing.

The ratchet arm is driven from an eccentric rod, the radius of whose attachment to the ratchet arm may be changed to increase or decrease the amount of feed for each revolution

of the eccentric. A spring safety stop in the eccentric rod limits the power which may be transmitted from the eccentric, to prevent breakage in case any foreign object blocks the motion of the stoker.

A stoker water box is a part of the standard stoker equipment. At the bridgewall, a bridgewall water box of forged steel 7¼ in. square outside, is carried transversely across the end of the stoker. The water box acts as an air seal at this point.

The water box is connected into the circulation of the boiler by boiler tubes expanded into counterbored seats.

A sprung arch, made up of standard firebrick shapes, is generally used in connection with this stoker.

Burke Traveling Grate.—This stoker uses natural draft for its operation. The grates are made up on a bar which are connected at the end to endless chains that operate around sprockets at the front and rear of the stoker.

The hopper ends are supported in front. An adjustable gate at front gives the desired thickness of fuel bed.

The front sprockets are driven by a nest of spur gears—which are operated from a line shaft.

Ignition arches are used with this stoker as well as water backs at the rear.

Coxe Traveling Grate.—This Stoker is designed to burn the small sizes of anthracite coal. (Fig. *19.*)

The fuel supporting surface consists of a number of parallel grate bars which are connected to endless chains forming an endless moving grate. Provision is made for introducing air under pressure under the grate with means for proportioning the volume and pressure of air under different parts of the fire as may be necessary.

Ignition and combustion arches are used over the grate to insure ignition.

Coal is fed to a hopper extending across the front end of the stoker above the grate from which it is deposited on the grate, the thickness of the fuel in the grate being regulated by an adjustable coal gate. Ignition takes place and combustion is supported by forced draft under the grates. There are three or four air compartments (Fig. *20*) each extending cross-

wise of the furnace, in each of which the air pressure may be independently regulated.

The stoker weighs approximately 450 lbs. per square foot of active grate surface. The side frames on which practically

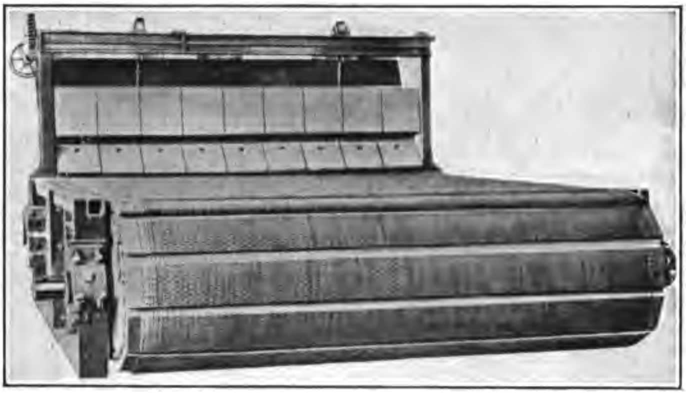


FIG. 19.—End View of Coxe Traveling Grate Stoker.

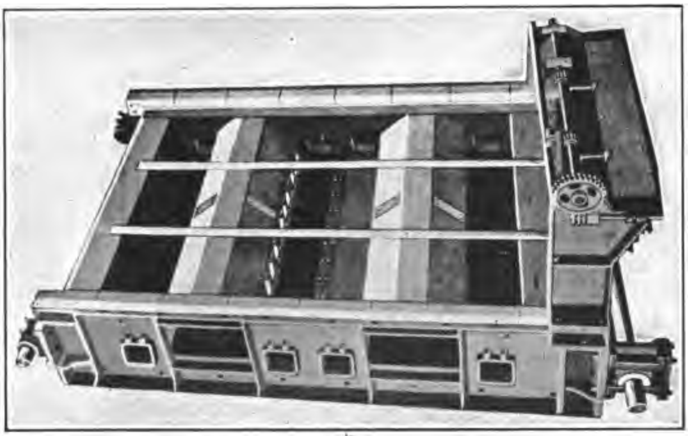


FIG. 20.—Elevation and Perspective of Coxe Traveling Grate Stoker.

the entire weight of the stoker is carried are iron castings of channel cross-section about 34 inches high with four-inch flanges. These frames carry on each end the shaft bearings or boxes for the driving shaft at the rear end and idler shaft at the front end.

Access to each tuyere box is made through a cast iron door located outside of boiler setting.

The fuel supporting surface is made up of keys or grate tops which are small castings approximately 3/4″ wide, 8″ long and 2″ deep. The top surface is curved, and the front end of each key matches the real end of the next key.

The chains are made of drop forgings held by steel pins.

The chains are carried over sprockets at the front and rear ends of stoker returning under the floor of the air compartments. The rear shaft is the driving shaft and extends through

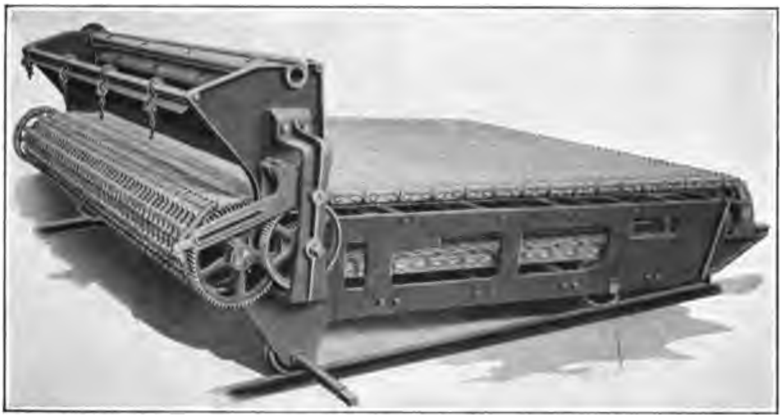


FIG. 21.—Green's "K" Type Chain Grate Stoker.

the side wall of boiler where it is keyed to a cast iron worm wheel mounted in a cast iron enclosed gear case.

Green Chain Grate.—Open hub links with vertical air spaces are used on this stoker type "K" (Fig. *21*) in making up the chain except those links which hold the chain together. Flattened cross bars are used instead of round and the link designed so that if the rod is turned on its edge the links can be removed individually.

The chain passes over sprockets at the front and rear; adjustment for the chain being provided for at the rear.

The upper part of the chain is supported by pipe rollers which, in turn, are supported by the side frames. The upper edges of these frames are set well below the top of the links,

this design being used to keep the frame away from the high furnace temperatures.

Air seals are provided at the rear by accumulation of ashes on the rear girder. This girder, in connection with the pipe rollers, form the air seal.

The side frames are maintained in their proper position by spacing beams, one at the front and one at the rear. In all wide stokers, a center support is used for the front and rear sprocket shafts and the upper roll shafts.

Diagonal bars are used to keep the frames at right angles. The frame is mounted on four track wheels so the stoker can be withdrawn from the furnace.

The coal hopper is formed of cast iron hopper ends and a sheet steel front plate. The feed gate is supported from a square shaft and moves between vertical guides, and is adjusted by a worm and sector attachment on the hopper end. The inner surface of the gate is lined with firebrick tile of special shape, and designed so that each tile can be removed individually.

The front sprocket shaft is driven by a ratchet, cast steel pawl and cast steel gear train, babbitted in a self-contained frame which is bolted to the stoker front side frames. The ratchet is operated from an eccentric on the main driving shaft, the eccentric rod being provided with a safety spring in case the grate is blocked for any reason in its motion.

A high pressure water box is used with the stoker at the bridgewall. The water box is connected into the circulation of the boiler by boiler tubes.

An ignition arch of the suspended type is used at the front of the stoker; specially formed firebrick tile being suspended from I-beams.

The stoker operates on natural draft.

"L" TYPE GREEN STOKER

This company also make the "L" Type stoker (Fig. 23) the important difference from the "K" Type being a fuel pusher and inclined coking plates in front of the chain grate. These inclined plates are designed to keep fuel broken up

during the first period of burning, and delivering it to the chain without large, unmanageable masses of coke. After the coal is coked on the front part of the stoker then combustion is completed upon the plain chain grates.

The Fuel Pusher is made as wide as the hopper. It is operated through an adjustable stroke giving a positive means of controlling the fuel bed. In this way the fuel bed is varied. The driving mechanism of the pusher plates is independent of the chain drive and of the coking plate agitators.

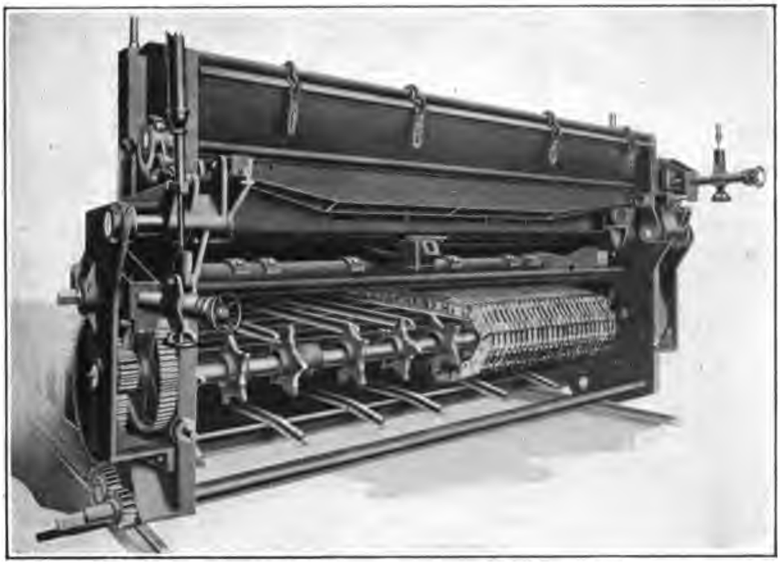


Fig. 22.—Front View Green " L " Type Chain Grate Stoker.

To maintain uniform density in the fuel bed during the coking process, the fuel pushers are provided with small adjustable sections each 12″ wide.

The inclined coking plates form an inclined grate area between the fuel hopper and the chain grate. Agitation is given to the coking plates to keep the fuel particles in motion.

The rear cross girder of this stoker is a semi-steel box maintained at low temperature by water circulation. It is designed to hold the stoker frame square and true.

The chain is kept at tension by worm gearing in cast iron

casings. These are interconnected and can be adjusted from the side. A water cooled surface is placed in the wall adjacent to the coking plates to prevent clinker adhesions and erosion of brick work.

A coking or ignition arch is used over the front part of the stoker. This arch is of special design of suspended type. High pressure water backs are used at the rear—connected up to the boiler circulation.

The stoker can be operated on either natural or forced draft.

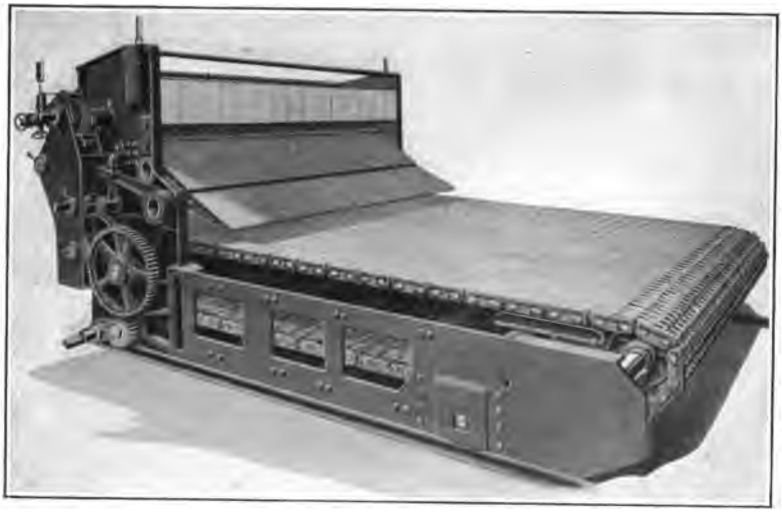


FIG. 23.—Green's " L " Type Chain Grate Stoker.

Illinois Chain Grate.—Natural draft is used with this Type "A" stoker (Fig. *24*). The links are about 9″ long, solid, and held together by link rods. The spaces in the link through which air passes to the fuel bed are placed at an angle and when the chain is assembled the angles of adjacent links cross each other. This design has been used in an attempt to reduce the sifting of fine coal, through the air spaces, to a minimum. The chain is slightly inclined from front to rear.

The chain passes over sprocket wheels at the front and rear. The rear sprockets are loose on the shaft. The front driving sprockets engage small rollers that are placed in between the

links. This construction differs from designs where the driving sprockets engage the links. Adjustment of the chain is provided by means of take-up screws at the front of the stoker.

The rollers upon which the chains travel are spaced about 12 in. apart, the roller rods being supported by side frames which are cast in a single piece, that is, the hopper supports and rear frames are one piece. The frames are held together by two cast-iron girders, one at each end, and diagonal tie rods from side to side maintain the frames at right angles. Air seals are placed at the rear of the frames.

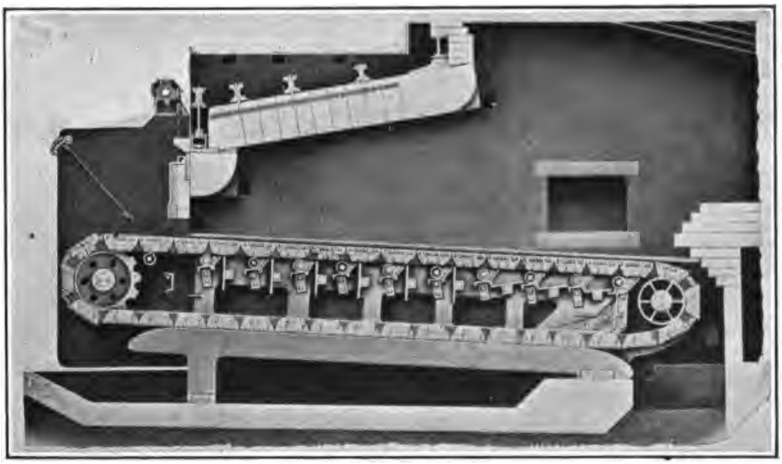


FIG. 24.—Type "A" Illinois Chain Grate Stoker.

The hopper ends are supported from the side frames, as shown in Fig. 25. The adjustable gate to give the desired thickness of fuel bed, is operated by a hand wheel at the side of the stoker which is connected to a shaft extending across the stoker by means of a worm and gear design. The gate is gradually raised or lowered. The inner surface of the gate is lined with special-shape firebrick.

The front sprockets are driven by a worm which engages a pawl and ratchet wheel operated by the eccentric on the drive shafting. The speed of the grate is varied from one to five inches per minute by moving a hand lever forward or backward, thus controlling the number of teeth on the ratchet wheel that the pawl engages at each stroke.

A low pressure water box made up of wrought iron pipe is generally used at the bridgewall.

A suspended fire brick arch is used, made up of special shaped blocks and suspended over the stoker.

This company also manufactures a Type "G"—(Fig. 25) forced draft chain grate stoker. The important feature of which is the system of dampered air control. Air required for combustion is delivered to a wind box which is incorporated in the side wall of the setting. The dampers for air admission to different parts of the grate surface are operated

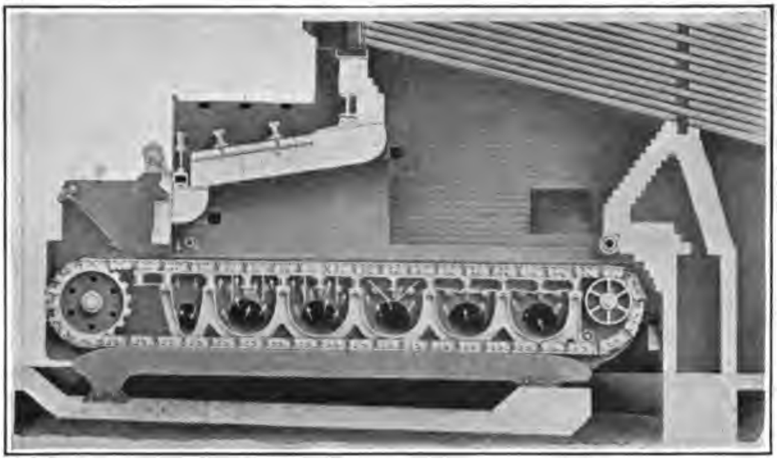


Fig. 25.—Type "G" Illinois Forced Draft Chain Grate Stoker.

from the side. The wind box is usually made of concrete and is the base of the side wall. Baffles are used so that air cannot pass through to the end of the grate. The mechanical operation of this stoker is practically like the Type "A" stoker, having sprockets in front—which are connected to a worm wheel and worm attached to the end of the front sprocket shaft. Rear drums are used similar to the Type "A" stoker. An arch is used for ignition purposes.

Laclede-Christy Chain Grate.—The links of this stoker (Fig. *26*), are all of the same design with the exception of the side links. They are about 9″ long with the air spaces at an angle. Cast iron rollers are placed on the link rods in

between the links and act as spreaders, and also engage the front sprockets. The chain in slightly inclined from front to rear.

The chain is driven by the front sprockets, keyed onto the shaft. The rear end of the chain passes over idler pulleys which are loose on the shaft. Take-up boxes are located at the front of the stoker.

The side frames are made of two pieces, the front part being bolted to the rear part. These side frames are held together by rods and pipe spacers and diagonal bracing, the

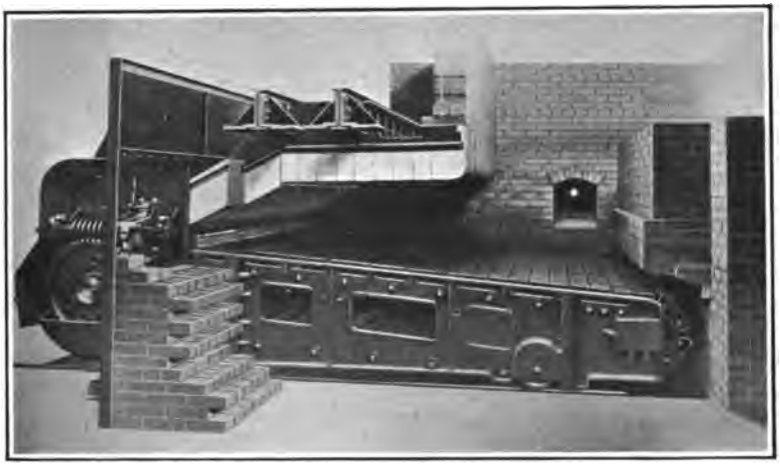


Fig. 26.—Laclede-Christy Chain Grate Stoker.

chain being supported on the pipe rollers, one at the top of the frame and one at the bottom. The entire frame is supported on four cast-iron flanged wheels which fit T-rails so that the stoker can be withdrawn.

The feed gate is adjusted by two hand wheels, one on each side of the stoker, and regulate the thickness of the fuel bed from 1″ to 10″. The inner surface of the gate is lined with special shape firebrick blocks having rounded ends where the coal is admitted.

Air seals are placed near the rear idler wheels and a second damper which can be regulated, placed 24″ to the front of the rear seal.

The driving mechanism consists of a worm gear operated by a pawl and ratchet which can be regulated to control the speed of the grate. The pawl is operated by an eccentric placed on the driving shaft.

A low pressure water box at the bridgewall and a suspended arch of special firebrick shapes is generally used. Natural draft is used with this stoker.

Continental Traveling Grate.—The chain of this stoker (Fig. 27), is distinctive in that grates are not interlocking as the ordinary link design. Natural draft is used.

The grates are designed and constructed of small units, with dovetail and semicircle for locking each grate, this dovetail

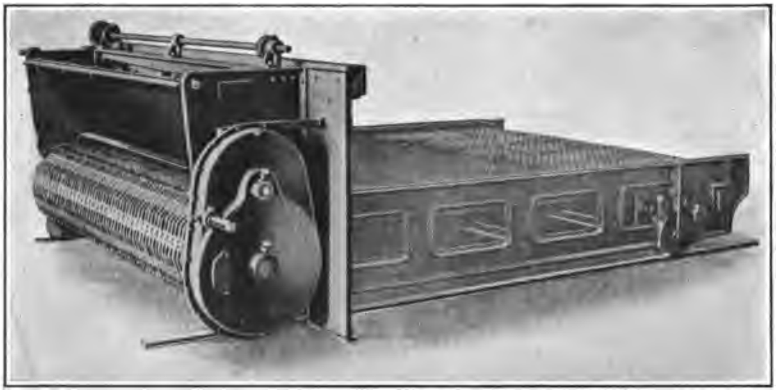


Fig. 27.—Continental Chain Grate Stoker.

being inserted into the openings in the links and bars, a rod passing through the cored hole locks each grate into its proper position. The grate can be removed and replaced, there being one rod which locks each section of grate in its position. This rod acts as a key to each grate. The grates are interchangeable and of one size.

An independent chain is used of links separated and bolted to cast-iron bars. These bars act as supports for grates.

The frame consists of two cast-iron side frames connected to two hopper frames, braced by four cross beams transversely to the frames, and two steel shafts upon which are mounted and keyed the sprocket wheels which impart the traveling

motion to the chain. The frame is mounted upon flanged wheels which rest upon rails set under the furnace so that the stoker can be withdrawn from the furnace.

The driving mechanism utilizes the double acting upward stroke of cams. The spur gear, consisting of a train of gears, is enclosed in a casing. The gears are driven by ratchet wheels and pawls, the ratchet wheels being operated by pawl levers connected to the speed adjustment links by rods which contain the relief springs. The adjustment links are connected to the roller levers and these levers ride on the cams of the line shaft.

A low pressure water box is used at the bridgewall and a flat suspended arch at the front of the stoker.

McKenzie Traveling Grate.—This stoker is of the traveling grate class, having the entire grate surface detachable and fastened to bars in small sections. This design has been worked out so as to make it possible to remove any grate bar independent of the others.

The entire stoker is built up with side frames which are supported on four wheels so that the stoker can be removed from the furnace.

The driving mechanism is made up of what is termed double-acting, giving a continuous travel to the grate surface, the speed of the grate being controlled by operating mechanism fastened to the side of the stoker part.

The stoker is also equipped with a clinker apron at the rear and a horizontal dumping grate, this dumping grate forming an ash receiver, this design being used to prevent, as much as possible, excess air at the rear of the grate.

The stoker is also equipped with a flat suspended ignition arch at the front and a low-pressure water box at the rear. Natural draft is used for the operation of the stoker.

Harrington Traveling Grate.—This stoker consists of cast-iron side frames, carrying the driving gear, hopper front shaft and feed gate in the usual manner (Fig. *28*). The side girders are formed of structural-steel members, built like a truss. Transverse members of structural steel support a series of tracks, on which run semi-steel chains, which carry and support the grate surface and take up the stress and tension of the

chain. These are provided with V-rollers to insure alignment both horizontally and vertically, and to reduce the power required for driving the stoker. An inclosed double worm drive is provided at the rear of the stoker. Attached to the chains is a series of transverse racks or beams on which the clips or bars forming the grate surface are attached.

The grate bars are sufficiently loose to slide over the ends of the racks. The straight under-surface of these racks make an air-tight diaphragm of seal between the adjacent compart-

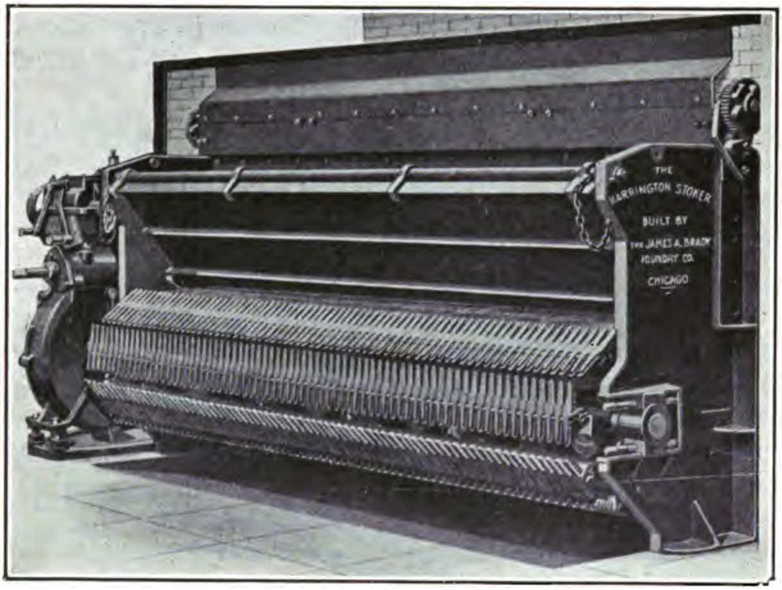


FIG. 28.—Front View, Showing Hopper Parts of Harrington Forced Draft Traveling Grate Stoker.

ments. These compartments occupy the space between the chains communicating on one or both sides to the air duct in the boiler side walls, or below the floor of the boiler room.

An adjustable damper serves to control the air pressure in the respective compartments. Each communicating passage through the side wall terminates in a removable door, which, when taken off, allows free access to the chamber. The closing of the damper and the removal of this door serves to put the stoker on a natural-draft basis.

The grate bars fit close together, and the air in passing through them makes two right-angle turns. The lower shoulder at the joint is designed to prevent the falling of fuel through the grate. Projections hold the adjacent surfaces apart so that an air space of approximately 15% is attained.

Fig. *29* is a view of the stoker partly assembled. It has four compartments, the one under the central part of the grate having double the width of any one of the others. Underneath the lower run of the grate an extension is built out over the ashpit to protect the bars from radiated heat, and a seal under the rear cross baffle is carried up as close as possible to the moving surface. These provisions obviate the need for a water-back or an overhang to the bridge-wall.

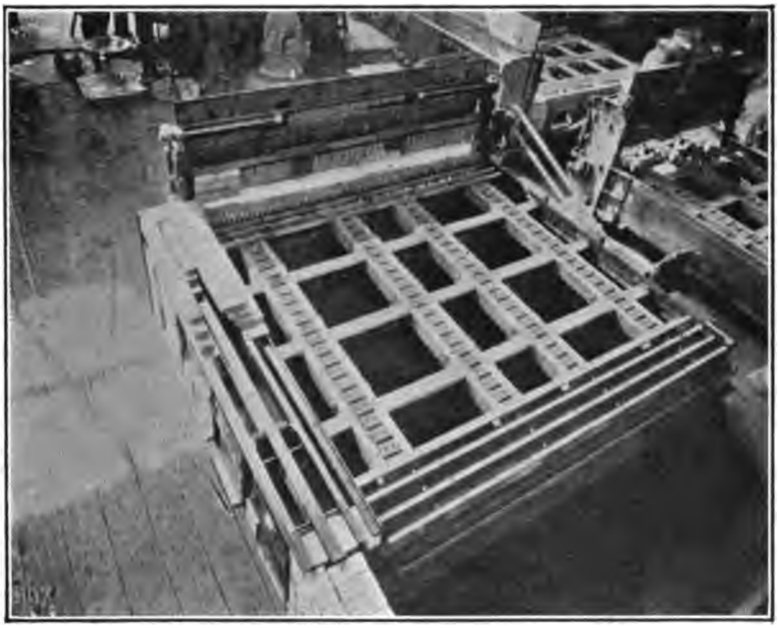


Fig. 29.—Harrington Forced Draft Traveling Grate Stoker Partly Assembled.

The chambers communicating between the compartments and the common air duct from the fan are shown in Fig. 29. The duct passes immediately below and a common damper plate in the bottom of each chamber controls the volume of air

to each compartment. The dampers are operated manually by means of the lever and hand-wheel shown. Each damper is set in accordance with requirements while the total air supply is controlled through the fan serving the stoker.

Playford Chain Grate.—This stoker (Fig. *30*) operates on natural draft. The chain consists of a number of driving and standard links with vertical air spaces, traveling in the form of an endless chain over supporting rollers at the rear. The motion is imparted by the sprocket wheels which are mounted on the front driving shaft, and engage with the rods supporting the grate links, which form the chain. Adjustment of the chain is provided by screws at the front of the stoker.

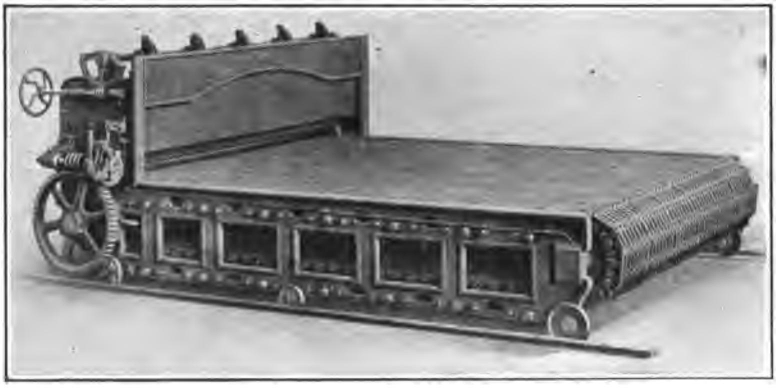


FIG. 30.—Playford Chain Grate Stoker.

The chain is supported by pipe rollers fastened to the side frames which are spaced by the usual cross beams. Air seals are provided at the rear of the stoker. The frame is mounted on wheels so it can be removed from the furnace.

The motion of the driving shaft is derived from a ratchet, worm and gear, located at the side of the stoker, and is transmitted through an eccentric from the line shaft.

The coal feed is regulated by raising or lowering a sheet steel water gate by means of a hand wheel located at the side of the stoker.

A low pressure water box at the bridgewall and an ignition arch, built of standard size firebrick and located immediately at the front of the stoker.

Stowe Traveling Grate.—This stoker (Fig. *31*) consists of traveling grates alternating with stationary tuyeres. The grate surface is inclined towards the bridge wall at an angle of twenty degrees. The stoker essentially is made up of coal hopper in front—where the coal is allowed to feed with the grate according to a thickness set by a feed gate. The chain grates are about 4″ wide and the tuyeres in between are about 3″ wide. The top of the tuyeres are depressed slightly below the chain. Near the bridge wall the grates rise to form a more horizontal grate

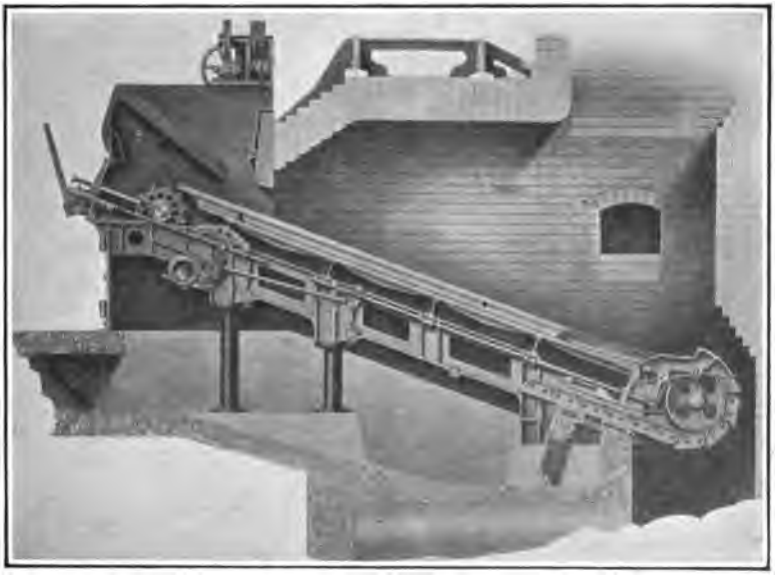


FIG. 31.—Stowe Conveyor Feed Stoker.

surface—this being designed to retard or hold back the fuel bed, if necessary, to burn all combustible matter left.

The chain elements are driven by sprockets keyed to a single shaft extending across the stoker in front. The main sprocket shaft is driven by an eccentric and ratchet arrangement through a nest of spur gears.

As the chain grates move down in the furnace and around the sprockets as in an ordinary chain grate stoker they are supported by cast iron skids. These skids also serve as a support for the tuyeres. A complete tuyere unit extends from the

dead plates in between the chain grates at the top to retarding bars in between the chain grates at the rear.

Air for the stoker is admitted from a chamber extending beneath the entire grate that serves as a wind box; at the rear is a concrete wall on which is mounted a series of cast-iron tunnels through which the returning chain grates pass.

A suspended arch is used with this stoker for ignition purposes—as coal is burned by the over feed method the same as a standard chain grate. A water back is not used however but if the ash pit is not sealed it would be necessary in order to

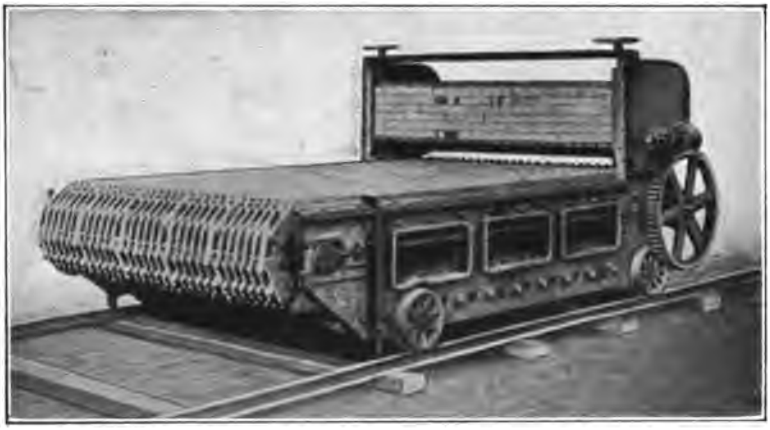


FIG. 32.—Westinghouse Chain Grate Stoker.

eliminate air leakage between the rear of the stoker and bridge wall.

Westinghouse Chain Grate.—The chain (Fig. *32*) is made up of standard and driving links with solid hubs 9″ long weighing 6 lbs. and 8 lbs., respectively. They are spaced and held together by steel rods.

The chain passes over sprockets at the front and rear. The front sprockets are keyed to the shaft. The rear sprockets are all connected together by pipe spacers and through bolts, and the entire unit revolves on a steel shaft supported by cast-iron bearings mounted in the side frames.

The upper part of the chain is supported on pipe rollers with cast-iron ends or bushings. These bushings run on steel

cross rods, spaced about 9 inches apart. The lower portion of the grate is supported on pipe rollers spaced about 18 inches apart.

The side frames are in one piece with removable top pieces that come flush with the top of the links. The frames are held together by a cast-iron beam at the front and a wrought-iron channel at the rear. Diagonal rods are also used.

The frame is mounted on four wheels of cast iron, so the stoker can be withdrawn from the furnace. The chain is level from the front to rear. Air seals are provided at the rear cross beam.

The hopper is made up of hopper ends bolted to the side frames and a steel front plate. The coal gate is supended from a channel supported on the hopper ends and adjusted by two hand wheels on each side of the gate. The inner surface of the gate is lined with standard arch and straight firebrick held together by cast iron clamps.

The chain is driven by a cast-iron worm gear which engages a cast-iron worm. Two mitre gears are actuated by a ratchet which, in turn, is driven by a pawl placed between two rods making up the ratchet arm. The ratchet arm is driven from an eccentric placed on the driving shaft. A safety spring is placed in the eccentric rod to prevent breakage.

A 4″ wrought-iron low-pressure water box is used at the bridge wall, and a sprung arch of standard firebrick at the front of the stoker.

Natural draft is used with this stoker.

OVERFEED TYPE STOKERS

Cox-Fulton Stoker.—This stoker is of the front feed class operating on natural draft (Fig. *33*). The coal hopper extends across the front of the stoker. The coal is fed to the coking plate and onto the inclined grate bars by a reciprocating pusher, operated by a sector on the hopper shaft. Motion is given to the hopper shaft by means of an eccentric on the main shaft. The motion of the pusher is adjustable. The grate supports are inclined to the rear about 39°.

The grate bars are water-cooled on their inner edges, steel

tubing being used to connect the grates to the water supply. Movable and stationary grates are used, giving a forward-upward-inward motion to the movable grates. Motion to the grates is obtained from a main shaft located in front of the stoker through eccentrics connected to inclined grate bar bearers. The movement of the grates forces the fuel bed to the bottom of the furnace on the dump grate.

FIG. 33.—Cox-Fulton Inclined Overfeed Stoker.

Dump grates and guards are operated from the front, and thus the ash and refuse is dumped into the ash-pit periodically. An ignition arch of the sprung or suspended type is used.

Model Stoker.—This stoker is of the side feed class having the coal hoppers on the side and operated on natural draft of from .25″ to .6″ in the furnace. The grates are arranged in pairs inclined from the sides to the center in a V-shape, one of each pair on each side being stationary and the other movable. When in operation, the movable grate is moved by the rocker bar up so its fire edge is a little above the fire edge of the stationary grate and then down a little below. The stationary grates rest at the lower end on the

bearer and at the upper end against the edge of the bottom plate of the magazine over which the coal is fed into the furnace. The movable grates are hinged to the stationary grates by a pin lug which fits into a hole in the stationary grate near its upper end, the lower end of the movable grate being held to place and rocked by the rocker bar as indicated.

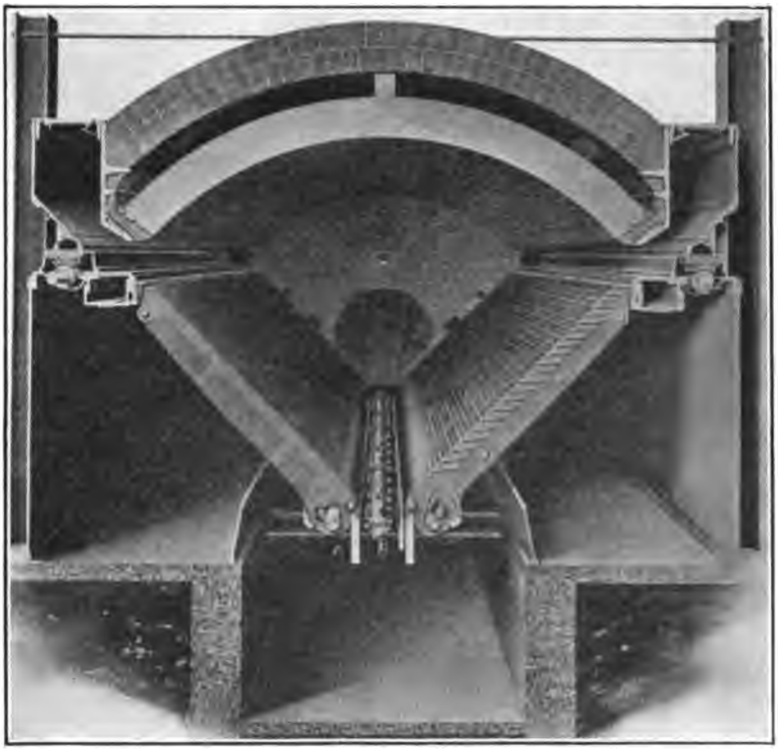


FIG. 34.—Murphy Automatic Furnace.

The grate bearer located in the center of the furnace supports the grates and forms a box-like receptacle into which the clinkers and ash pass and are ground out into the ash pit.

A sprung arch is used over the V-shaped grates, and air admitted at the point where the volatiles are distilled from the coal as it comes from the stoker coal hoppers.

Murphy Stoker.—The Murphy stoker is of the side feed class, having the coal hoppers on the sides with inclined fires

on both sides of the furnace and the observation door and operating mechanism in the front (Fig. *34*). This stoker uses natural draft.

At either side of the furnace, extending from front to rear, is a coal magazine into which the coal is introduced by conveyors. At the bottom of this magazine is the coking plate against which the inclined grates rest at their upper ends. The stoker boxes, operated by segment gear shaft and racks. push the coal out over the coking plate and onto the grates.

The grates are made in pairs, one fixed, the other movable. The movable grates, pinioned at their upper ends, are moved by a rocker bar at their lower ends, alternately above and below the surface of the stationary grates. The stationary grates rest upon the grate bearer which also contains the clinker or ash grinder. This grate bearer is cast hollow and receives the exhaust steam from the stoker engine. This steam escapes through small openings spaced at regular intervals on either side of the clinker grinder and lower ends of the grates to soften the clinker and to assist the cleaning process.

As the coal leaves the magazine, it rests upon the coking plate. The volatile gases are driven off and mixed with the heated air admitted through the air ducts in the arch plate. The coal, having been coked, travels down the inclined grates toward the clinker grinder, receiving air in the ordinary way through the grates to complete the burning process.

The speed at which the stoker boxes push the coal on the grates can be regulated to conform to the duty required. Likewise, the clinker grinder can be turned slower or faster according to the amount of ash in the coal.

A sprung arch is used extending from one hopper to the other.

Detroit Stoker.—This stoker uses natural draft and is of the side feed class having the coal hoppers on the sides of the stoker front (Fig. *35*). From the hopper, the coal is fed into the magazines by a worm coal conveyor. The gears operating the worm conveyors are lubricated by running in oil, and are covered with shields. The coal conveyors are operated by the upper shaft in front at a slow speed and distribute the coal at the upper end of the inclined grates on a coking plate.

Inclined grates of two kinds are used, i.e., stationary and moving, each alternate grate being operated by the driving shaft in front. The vibrating or operating grates have a motion forward and backward, moving the bed of fire down toward the center of the furnace.

The vibrating grates are operated by upper and lower rocker bars connected to the lower driving shaft by links,

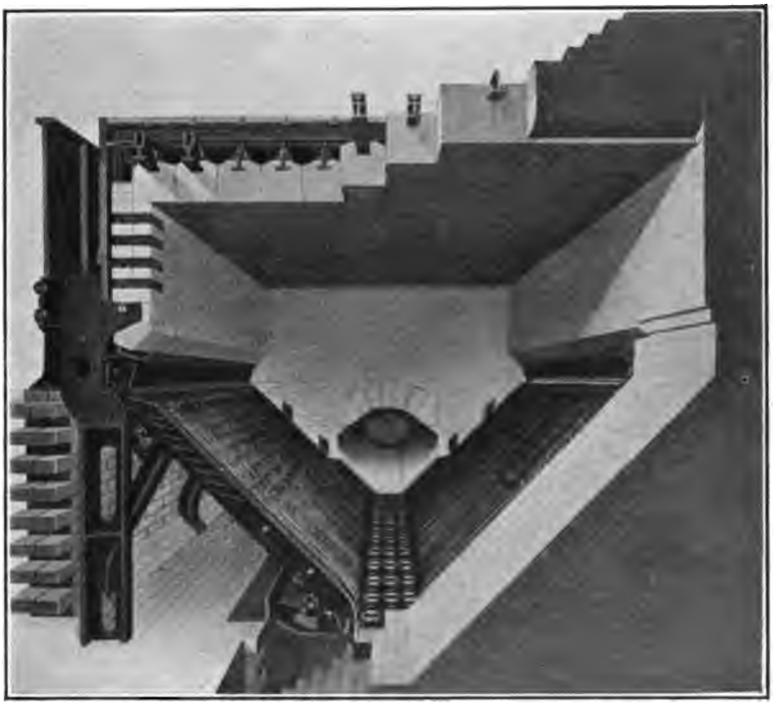


FIG. 35.—Detroit " V " Type Overfeed Stoker.

which can be unhooked during the operation, thereby discontinuing the grate movement entirely when desired.

In the center of the stoker, and at the bottom of the inclined bars, is a clinker crusher composed of a row of cast-iron discs, ten inches in diameter, which rotate alternately toward and from each other by the reverse gear and is connected with the front driving shaft. This serves to crush the clinkers and deposits them in the ash pit.

A sprung or suspended arch is used with this stoker and air admitted through channels forming the support for the arch skewbacks, this air being admitted where the volatile gases are distilled. An observation door is placed in the stoker front to observe conditions of the furnace.

Roney Stoker.—The Roney stoker (Fig. *36*) operates on natural draft and belongs to the front-feed class, the coal being fed from a hopper at the front of the furnace.

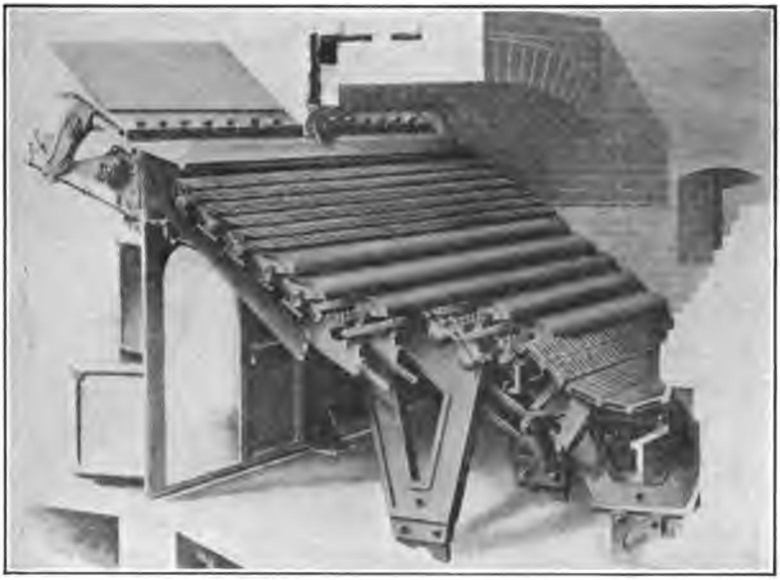


Fig. 36.—Westinghouse Roney Stoker.

From the hopper, the coal is pushed by an adjustable pusher onto a coking plate where the volatiles are distilled. From the coking plate the fuel passes to the grates. The grates consist of cast-iron webs on which are placed narrow grate bar tops. In the upper part of the furnace, flat overlapping bars are used to prevent sifting of fine coal. Each web is supported at its ends by trunnions and is connected by an arm to a rocker bar which is slowly moved to and fro by an eccentric on the shaft on the stoker front so as to rock the grates back and forth between a horizontal position and an inclination

towards the back of the furnace. The grates thus gradually move the burning coke downwards.

The ashes and clinkers are deposited onto the dumping grate which can be lowered by means of rods from the front of the stoker so as to drop the ash into the ash-pit below. A guard may be raised so as to prevent coke or coal on the grate bars from falling into the ash-pit when the dumping grate is lowered.

Air for the volatile gases is admitted in small jets at the front of the stoker. A firebrick arch is used at the front made up of standard firebrick shapes.

The stoker shaft on the front of the stoker is operated at 7 to 14 R. P. M. by a small engine through a worm and gear reduction. Doors are provided on each side of the hopper for observation of furnace conditions.

Wetzel Stoker.—This stoker operates on natural draft and is of the front-feed class, since the coal is placed in a hopper at the front of the furnace (Fig. *37*). From this hopper, the fuel is pushed over the dead plate and onto the coking grate by the feeder, moved by an eccentric on the shaft. The coking grate driven by a link connection to the feeder moves the coal onto the main grate.

The main grate consists of a series of movable, and a series of stationary bars, the bars of one series being alternately arranged with respect to those of the other. The grates are mounted on a stationary cast-iron frame, the stationary grates being directly attached thereto and the movable grates supported by rock shafts. The movable bars are driven by an eccentric on the shaft operating through a bell crank. The motion of the bars moves the fuel down the main grate which is inclined at about 30°, and discharges the ash onto the dumping grate. When sufficient ash has been accumulated on the dumping grate, a lever is thrown from the front of the furnace and the ash is discharged into the ash pit.

The coking grate contains an extremely large percentage of air spaces, the upper part of the main grate a somewhat smaller percentage, the lower part of the main grate still less, and the dumping grate a very small percentage.

Above the dead plate, coking grate and the upper part of the main grate is sprung a firebrick ignition arch.

The amount of motion of the feeder of the coal and motion

FIG. 37.—Wetzel Front Inclined Overfeed Stoker.

of the grates is adjusted from the front of the stoker by means of hand-wheels on the eccentric rods.

An inspection door is provided at the front on each side of the hopper enabling the operator to view the condition of the fire.

The main shaft which runs along the stoker front below

the hopper is driven by a steam engine operating through a worm gearing.

Wilkinson Stoker.—The Wilkinson stoker (Fig. *38*) is of the front-feed class and designed more particularly for the burning of fine anthracite coal. The coal hopper extends across the front of the stoker. A pusher fastened to the upper end of each grate bar pushes the coal from the hopper through the opening in the furnace front onto the bars. The grates are inclined about 30° and the motion of the bars gradually

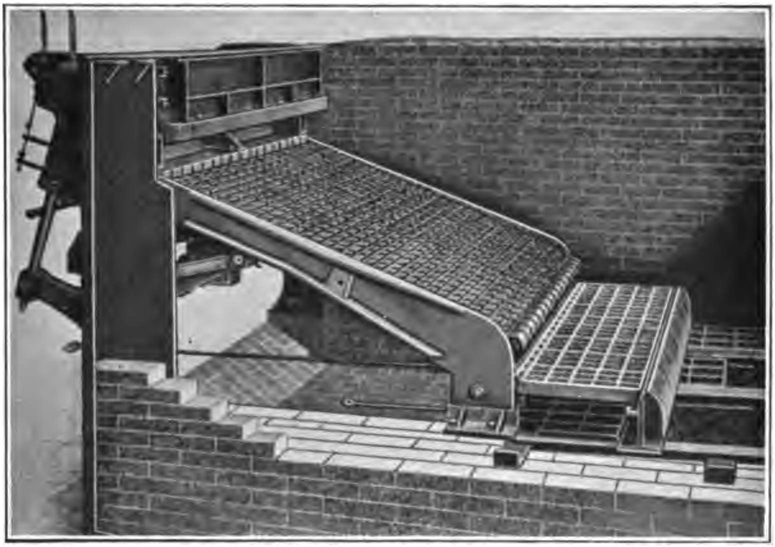


FIG. 38.—**Wilkinson Front Inclined Overfeed Stoker.**

moves the coal downwards, and deposits the ashes and clinkers on the clinker grates, from which they are finally pushed into the ash pit. The grate bars are cast hollow with nearly horizontal openings leading from the interior of the bars through the risers of the steps that form the upper surface of the bars. Each grate bar is given a to-and-from motion in a horizontal direction by the rock shaft and links, the ends of the bars being supported by, and sliding on, the hollow cast-iron bearing bars. Practically all the air from the combustion of the coal is drawn into the upper ends of the hollow

grate bars by the steam jets, and forced into the fire from the openings in the tops of the bars. A sprung or suspended arch is used with this stoker at the front.

UNDERFEED STOKERS (Multiple Retort)

Riley Stoker.—The Riley stoker (Fig. *39*) is of the multiple inclined retort class, using forced draft for its operation. Essentially, it is made up of individual retorts each having horizontal plungers for feeding the coal (about 12 to 15 pounds of coal being fed per stroke), reciprocating retorts, inclined about 20 degrees, moving overfeed grates, and adjustable

Fig. 39.—Riley Multiple Retort Underfeed Stoker.

apron refuse supporting plates, each retort weighing about 4,000 pounds.

The fuel-feeding mechanism is made up of cylindrical horizontal rams, 9″ in diameter, set about 19″ centers. These rams or plungers are connected to the crank shaft by connecting rods. All ram boxes are set in line and bolted to angles. The crank shaft bearing brackets are bolted to the ram boxes and tie them together. Crank shafts are made in sections, each section being driven by a gear box.

Reduction gearing is used to drive the main crank shaft. The main worm on the crank shaft is driven by a worm mounted on a supported shaft. This shaft carries a cut worm

wheel which is driven by a hardened steel worm mounted on the speed shaft of the stoker. The reduction through the gears, that is, the ratio of speed shaft to crank shaft, is 330 to 1. The speed shaft drive may be taken from any convenient source, usually from a line shafting running about 400 R. P. M.

A ½″ shearing pin is used in the connecting rod to provide against breakage of parts, should the rams become obstructed in any position of its stroke.

The retorts of the underfeed section are inclined about 20°, and the reciprocating movement is obtained by side rods driven by extension of the main plunger wrist pins. The side

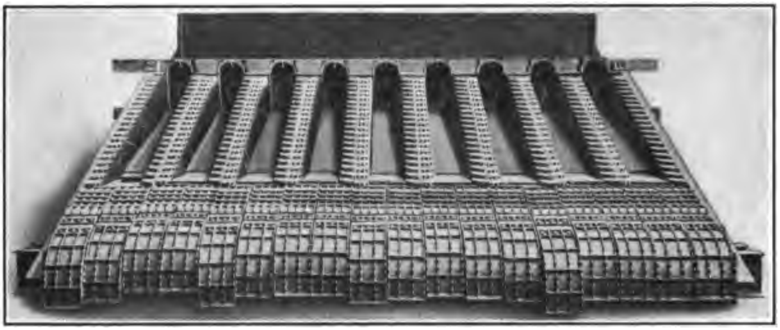


FIG. 40.—Rear View Riley Multiple Retort Underfeed Stoker.

rod bolts withdraw the side bars to the same position on each return stroke. The travel towards the bridge wall is varied by changing the amount of lost motion between the wrist pins and side rod by adjusting blocks. The retorts move a maximum of 1″.

On top of the retort sides are placed tuyere blocks with openings for air admission to the fuel bed. These tuyeres interlock and are bolted together.

The overfeed grates (Fig. *40*) extend the full width of the stoker, and are made up of unit retort width. They reciprocate back and forth practically the same as the reciprocating retorts.

The refuse supporting plates are hinged together by chains to form an apron, which hangs down over the ends of adjust-

able racks. These racks are set by hand to the size of the opening.

Air is admitted under the front of the stoker and forced through the tuyeres to the fuel bed. A damper is placed between the main air chamber underneath the front of the stoker and the overfeed reciprocating grates so that air can be regulated for this part of the stoker.

Jones A-C-Stoker.—The Jones A-C-Stoker is a gradual development from the original single retort Jones-Stoker. The A-C stoker is of the inclined, multiple retort class using forced draft for its operation. The stoker is essentially made up of horizontal rams—inclined retorts—stationary overfeed sections, and single dumping grates (Fig. *41*).

The fuel is fed to the furnace from the hopper located directly in front of the stoker by horizontal steam operated rams. In the underfeed section the volatile gases are distilled and the fuel bed progresses onto dead plates at the rear of the retort and then onto the dump grates.

The fuel feeding mechanism consist of a steam cylinder for each retort. A ram is connected to the piston of this cylinder. When steam is admitted into the cylinder through an automatic control valve—the ram is drawn outward and a charge of coal falls into the ram case. The automatic control valve reverses the stoke and the charge is forced into the retort.

A rod is connected to the ram and travels through the front end of the retort below the ram with each operation of the steam piston. On this rod inside the retort are bolted two pusher blocks so that the coal is carried upward and rearward with each stroke of the ram.

The dump plates are made in sections and are hinged to a shaft located at the rear of the overfeed sections. The dump plates projects towards the bridge wall, and are balanced and operated from the side of the furnace.

The standard tuyeres are fitted to the retort sides—and so formed so as to make a continuation of the retort, rounding off on top. Special side tuyeres are used reaching quite high above the side wall—air is circulated through these tuyeres—and they are so designed to keep the fuel bed away from the

brickwork of the side wall and in this way prevent clinker formation and bridging over the retort.

A distinct feature of this stoker is the control valve. It is installed in the steam line to each stoker cylinder and has eight rates of operation. The length of the stroke of the pusher

FIG. 41.—Jones' " A–C " Multiple Retort Underfeed Stoker.

blocks can be adjusted by changing a pin on the connecting bars below the rams.

Air is admitted to an air chamber below the retorts from the main air duct; from this chamber the air goes through the main tuyeres, the side tuyeres and the overfeed section. Air distribution boxes are used at the front above the mouth of the retort.

Taylor Stoker.—The Taylor stoker (Fig. *42*) was the first of the multiple retort class using forced draft for its operation.

The stoker is made up of two horizontal plungers or rams, one above the other, and connected together by links for feeding the coal; stationary retorts inclined about 22°; an oscillating overfeed section; and a single leaf dumping grate, each single retort weighing about 5,000 pounds.

The coal from the hopper discharges into a cylindrical chamber in which the 9″ diameter upper ram works. This ram is operated by a crank shaft at right angles which is driven by a worm and gear. The distance from center to

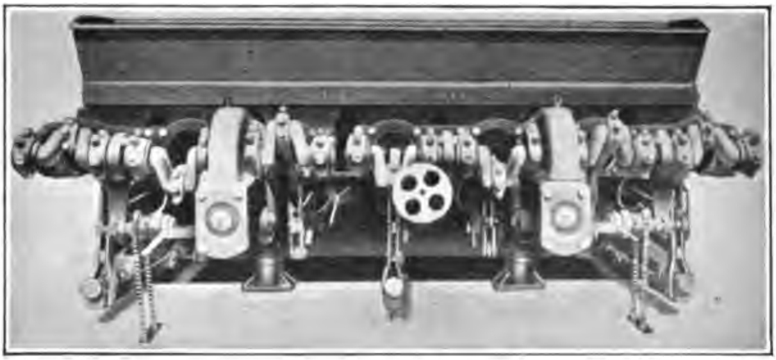


Fig. 42.—Type "AA" Taylor Multiple Retort Underfeed Stoker.

center of each ram is 20¾″, this being a unit retort width. A single speed shaft drives the series of worms and gears enclosed in a gear box. The ratio of speed shaft to the main crank shaft is 352 to 1. The lower horizontal plunger or ram is connected to the upper one by means of links, and its lost motion is adjustable.

Bearing brackets for the main crank shafts are bolted to the ram boxes and serve to tie them rigidly together. These bearings are babbitted and provided for lubrication. This shaft operates clockwise (looking from the right side of the stoker at the end of the shaft), the shaft operating from one revolution in 45 seconds to one revolution in a minute and a half.

In order to provide against damage due to any foreign substances that might block the action of the rams, a shearing pin is provided in the speed shaft and the parts so designed that stresses are transmitted to this part of the mechanism.

In the standard stoker, 17 tuyere blocks are used, set immediately on top of the tuyere boxes. Each tuyere block hooks into recesses and interlock with each other, thus holding them in place.

The air for combustion is forced from the wind box through the tuyeres to the fuel bed and controlled by suitable dampers.

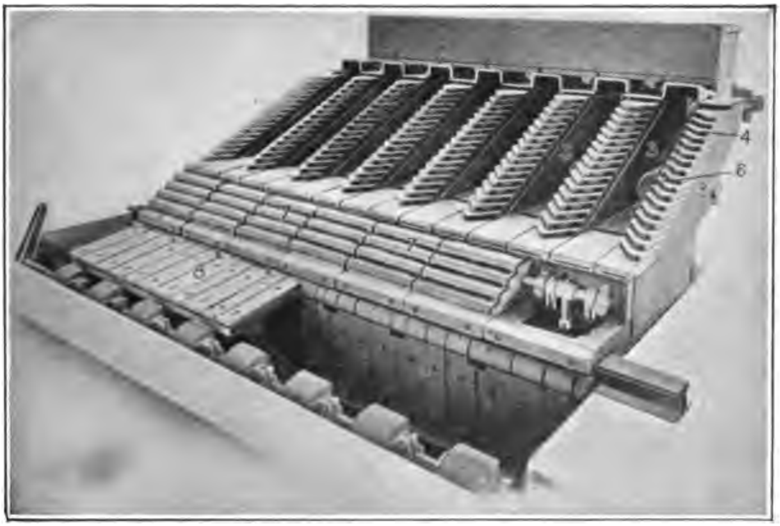


Fig. 43.—Rear View Taylor Type " AA " Multiple Retort Underfeed Stoker.

The air for the oscillating overfeed section is also controlled by dampers.

The dumping grates (Fig *43*) are made up of frames to which are fitted interchangeable grate bar tops, these being of the unit retort width. The dumping grate is operated by means of levers in front of the stoker.

The stokers for different size furnace widths are built up by a number of retorts. For example, the furnace for a 500-H. P. boiler might be made up of six retorts.

Different lengths from the front wall to the bridge wall are used. In some cases, the dump grates are operated by power

and in special installations a clinker grinder is used for ash disposal.

Westinghouse Stoker.—The Westinghouse stoker (Fig. *44*) is a multiple retort inclined about 20°, and uses forced draft for its operation. The stoker is essentially made up of downward inclined rams, inclined retorts, a reciprocating overfeed section and double dumping grates.

The fuel is fed to the furnace from the hopper proper by downward inclined rams equal in number to the retorts in

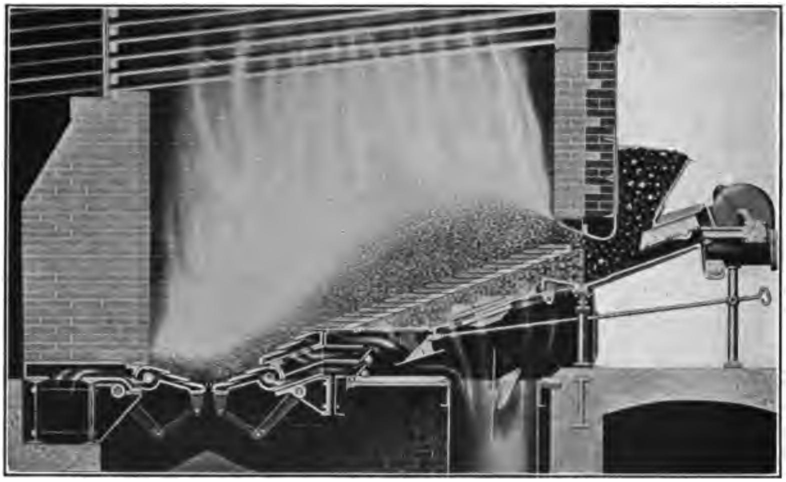


Fig. 44.—Westinghouse Multiple Retort Underfeed Stoker.

the furnace. In the underfeed section, the volatile gases are distilled and the fuel bed progresses on to the overfeed section and then on to the dumping grates. About 18 lbs. of coal is pushed into the underfeed section with each stroke of the ram.

The fuel-feeding mechanism consists of a 9″ plunger or ram operating in an inclined cylinder forming part of the ram box, these rams being set 21″ centers. These rams obtain their motion through connecting rods to cast steel crank shafts 3½″ diameter, these being made up of units and connected together with bolts.

Bearing brackets for the crank shafts are bolted to the ram boxes and, in this way, tie them together. These bearings in

the brackets are babbitted and provided with grease cups for lubrication. This shaft operates from one revolution in 45 seconds to one revolution in a minute and a half.

The reduction worm gearing is used to drive the crank shaft. The main power worm gear is connected by bolts to the flanges of the crank shaft, and is driven by a worm mounted on a cross shaft supported in the gear box. This shaft, in turn, is driven by a bronze worm gear and hardened steel worm fitted to the speed shaft. One gear set is used to drive a maximum of four retorts. A hinged cover on the gear case is provided to make inspection. The speed reduction in the gear box is 352 to 1.

A protective device, consisting of a 3/32″ shearing pin, is provided in connection with the speed shaft to guard against damage of stoker parts, should foreign substances be accidentally admitted with the coal and block the movement of the rams.

The lower ram is operated by means of connecting rods, through lost-motion mechanism, to the upper ram. It reciprocates along the bottom of the retort, and in the same plane as the main ram.

Above the upper end of the tuyere boxes, and extending laterally across the furnace, are air distributing boxes which are bolted to the ram boxes. These are made of unit retort width, cast hollow, and designed to transmit part of the load of the front wall to the tuyere boxes.

A fuel deflecting plate is provided in the retort for varying the thickness and outline of the fuel bed.

The forward and rear dumping grates are made up of frames to which are fitted interchangeable corrugated grate bar tops, and in this way a passage for air is formed. These are made of the unit retort width, the lower grate bar top being bolted so as to lock the other tops in place. The forward dumping grate is pivotally connected to the dump grate brackets, and projects towards the bridgewall, and the rear dumping grate is supported in a similar manner and projects towards the front of the stoker. Both dump grates are operated from the side of the furnace.

The overfeed grate is of unit (Fig. *45*) retort width, and is

operated by the upper ram through rods and lost-motion connection. The rods return the overfeed grate to the same position on each stroke. The travel forward is adjusted by changing the amount of lost-motion by means of collars. These are placed on the rods from the front of the stoker.

The furnace is sealed from the stoker front to the rear of tuyere boxes by means of a reinforced concrete floor. Dampers are provided and set in the floor to control the air from the main air ducts. Auxiliary dampers divide the wind box transversely. Doors are placed in the front for access to the wind box and for air admission when the stokers are being operated on natural draft.

FIG. 45.—Rear View Westinghouse Multiple Retort Underfeed Stoker.

The tuyere boxes used with the stokers are of the box girder type. Their front ends are bolted to the ram boxes and rest on angles supported from the floor. Their rear ends are tied together. The ribs on the sides of the tuyere boxes are used for supporting the retort bottoms.

The tuyeres are of corrugated construction and hooked into the recesses in the top of the tuyere boxes and interlock with each other, thus holding them in place. In a stoker 10 ft. from the front wall to the bridge wall of the double dump grate type, 17 tuyeres are used. They are laid, one upon the other, and the entire block is locked by means of the upper tuyere.

Air admission to all parts of the furnace is controlled from the front or side of the stoker. Air is admitted to air distributing boxes located at the front for air above the fuel bed.

The air through the underfeed section is forced from the

wind box through the tuyeres to the fuel bed, and controlled by dampers. Air admission to the overfeed section and dump grates is also controlled by dampers.

Frederick Stoker.—The Frederick Underfeed Stoker is of the general inclined multiple retort type, having horizontal rams; stationary underfeed sections, and air admitting dumping grates.

The retorts are spaced 21 inches apart and have a main feeding ram $9\frac{1}{2}$ inches diameter, feeding approximately 20 pounds of Eastern fuel per stroke.

The underfeed section is inclined 20 degrees from the horizontal and the usual extension grate common to this type of stoker is eliminated.

The secondary rams are operated by suitable connection to the main ram mechanism and the stroke of this ram is controlled by means of a shaft located above the retorts in front which engages or disengages the dogs fastened to the moving rod; thus increasing the stroke of the secondary ram to a maximum of 6 inches or allowing it to operate at normal stroke.

The shearing pin arrangement is located in the speed shaft mechanism as is common with other stokers of this type. In order to obtain two sets of speeds for the rams, there are two sprockets placed on the speed shaft and by operating these through a clutch arrangement one or the other ratio of speeds can be used.

Refractory blocks are used in the front wall and bridge wall immediately over the stoker parts.

UNDERFEED STOKERS (Single Retort)

Jones Stoker.—The Jones stoker (Figs. *46* and *47*) is of the single retort class essentially consisting of one horizontal retort with plates on the side for supporting a fuel bed as it is pushed out of the retort. Forced draft is used with this equipment.

The fuel feeding mechanism consists of a small hopper bolted onto the ram case, which, in turn, is bolted to a steam cylinder, all of this mechanism being outside of the furnace.

Steam is admitted behind the piston which forces the piston and ram forward carrying a portion of the coal in the hopper

to the retort. Pusher rods are provided in the retort to carry a portion of the coal forward in the retort.

FIG. 46.—Sectional Front View Jones Single Retort Underfeed Stoker with Side Plates.

The retort consists of a fuel magazine with tuyere blocks attached to the top of the retort. These tuyere blocks are made in unit sections and are fastened to the retort by one single rod.

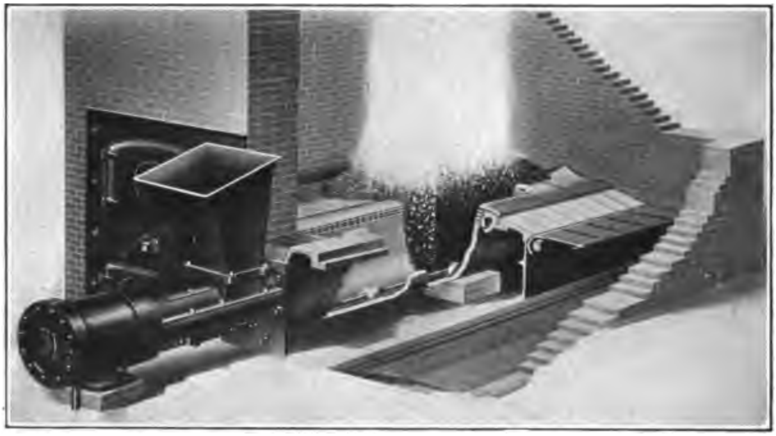


FIG. 47.—Jones Single Retort Side-dump Underfeed Stoker.

Air from the blower is forced into a sealed ash pit from which the air passes through the hollow tuyeres to the fuel bed.

The dead plates on the side are ribbed and the air circulates under them and through the tuyere blocks. No air is admitted through them.

The operation of the steam rams are controlled by means of automatic valves, each ram being adjusted independently of the other. The rate of feed can also be adjusted within a certain range of operation.

Doors are placed in the stoker front for use in cleaning the fires as the ash is separated from the incandescent fuel bed and pulled out of these doors.

Moloch Stoker.—This stoker is of the single retort class using forced draft. A retort runs lengthwise of the furnace into which the fuel is pushed by a steam ram. Above the retorts

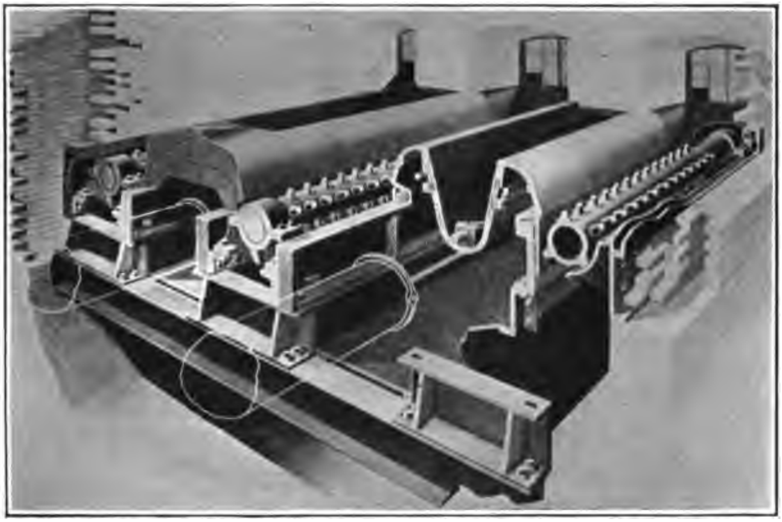


FIG. 48.—Moloch Single Retort Underfeed Stoker.

are tuyeres to supply the air to the fuel bed, and on either side is a rotary grinder disposing of the refuse. The fresh fuel is fed underneath the zone of combustion, there being no moving or stationary grates to provide for overfeed burning.

Fig. *48* is a perspective of a two-retort equipment. The retorts are inclosed by cast-iron air boxes with the air supply for each controlled independently by an air gate operated from the front of the boiler. Each stoker unit is supported at the front and at the bridgewall.

The retort has a horizontal top on which are mounted tuyere blocks to provide air under pressure, the fuel being fed to

the retort by a steam operated ram supplied from the hopper attached to the ram cage. The operation of the ram is intermittent and automatically regulated, each charge delivering coal to the retort. The tuyere openings supply the air for combustion below the fire and above the fresh fuel. The heat of the fire above drives off the volatile matter, and these gases

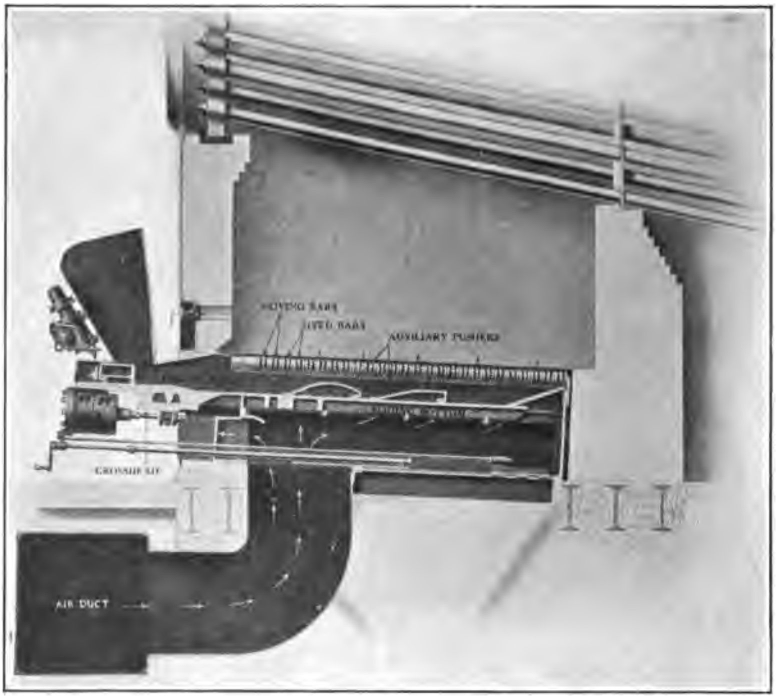


Fig. 49.—Type "E" Single Retort Underfeed Stoker.

mix with the air supply passing through the zone of combustion. The coke passes upward and out of the retort and above the grinders, the refuse passing over the tuyere blocks to the rotary grinders.

Type "E" Stoker.—The Type "E" stoker is of the single retort class and uses forced draft.

The coal is fed into a hopper on the outside of the furnace. From this hopper (Fig. *49*) the fuel is delivered by gravity to the front end of the bottom of the retort, and is then pushed

into the furnace by a steam-driven feeder block until the retort, which runs the length of the furnace, is filled.

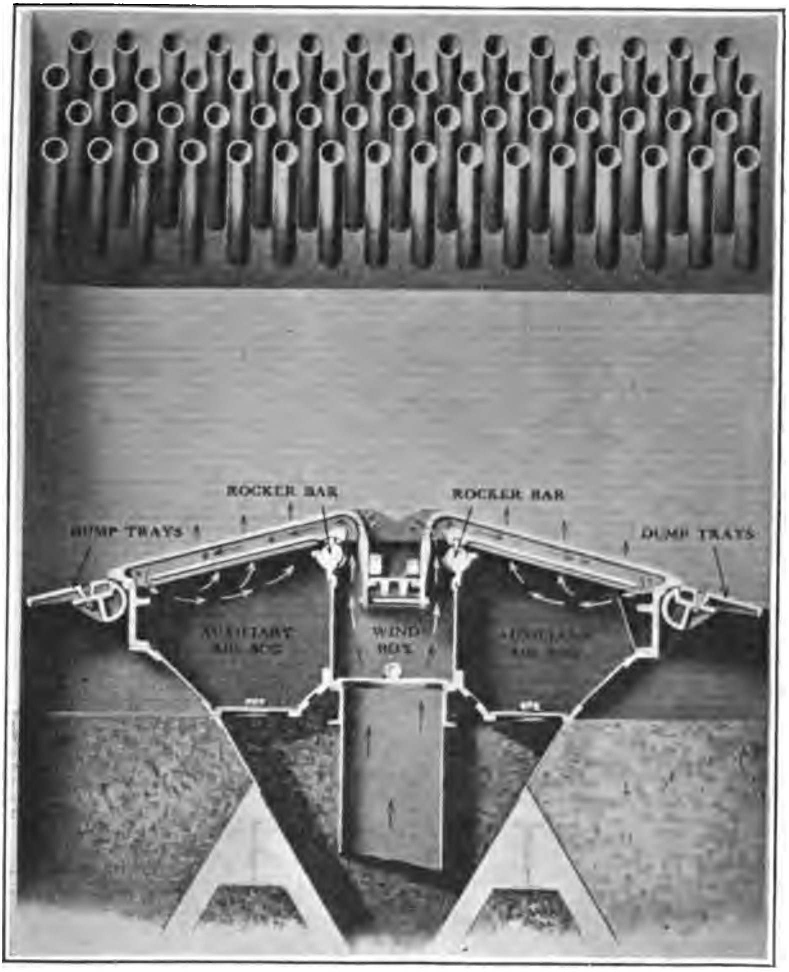


FIG. 50.—Cross Section Type "E" Single Retort Underfeed Stoker.

As the coal rises in the retort, it is flooded on the fire-bars (Fig. *50*) by the movement of auxiliary pushers. The grate bars are arranged alternately moving and fixed and reciprocate with the movement of the pusher, spreading the coked fuel toward

the side or dump plates. The movement of the fire-bars also conveys the clinker and ashes to the dump trays.

The bars are slightly inclined, but not enough to cause a gravity travel of the coal. The fire is kept moving by the mechanical movements of the bars, obtained by means of two helices and nuts placed outside the furnace. These cause the moving bars to rock to and fro.

Each stoker has an individual drive, but by means of automatic control all are run at a uniform speed. A stoker may

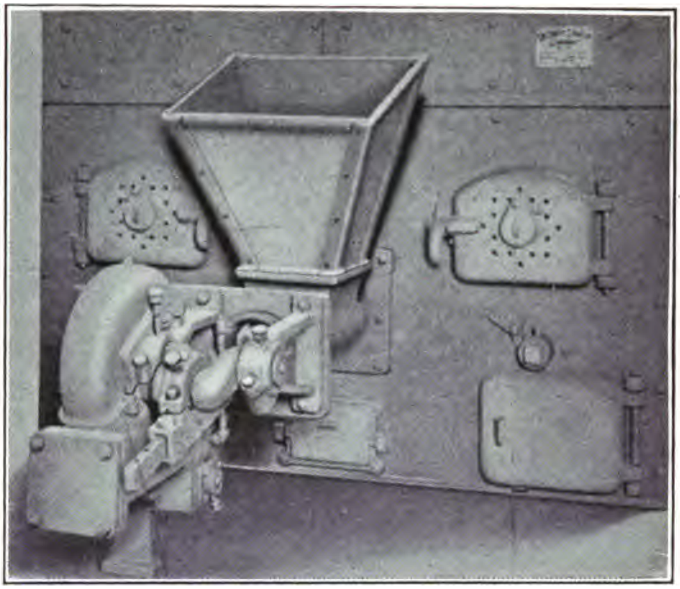


FIG. 51.—Detroit Single Retort Underfeed Stoker.

be cut in or out of service by throttling the driving engine and shutting off the air.

Detroit Underfeed Stoker.—This stoker (Fig. *51*) is of the single retort type and uses forced draft for its operation. It consists of a horizontal retort with side grates for supporting the fuel bed as it is pushed out of the retort, and dumping grates on each side for cleaning purposes. It has mechanically operated plungers, or rams, connected through a reduction gear to a shaft located in front of the stoker. All the gears, worms

and moving parts are enclosed in a gear box. This gear box is similar in construction to the gear box used on the multiple inclined underfeed stokers.

The stoker consists of a coal hopper in front, and the retort proper, extending into the furnace. Connected to the ram or plunger is a pusher block located in the bottom of the retort and is used to feed the coal the entire length of the fuel bed.

FIG. 52.—Rear View Detroit Single Retort Underfeed Stoker.

Tuyere blocks for distribution of the air to the fuel bed are made of unit sections, and are fitted to both sides of the retort.

Air from a blower is forced into sealed compartments from which it is directed by the tuyeres to the fuel bed.

The grates on each side (Fig. 52) of the retort are ribbed, and are made to extend from the tuyere blocks to the dumping grates, located at the sides. The dumping grates are solid, without air admission, and are operated from the front of the stoker.

The operation of the mechanical rams is taken from the crank shaft and controlled by lengthening or shortening the

stroke of the connecting rod. Each ram being adjusted independently. The rate of feed can be adjusted within a certain range of operation.

Doors are placed in the stoker front for use in cleaning fires, these doors are located immediately in front of the dump grates and a view of the fires can be had at all times from the front. Ash pit doors are also located in the stoker front, so that ashes can be cleaned out from the front of the stoker.

Roach Stoker.—This stoker is of the single retort type—with side grates and dump grates next to the furnace wall.

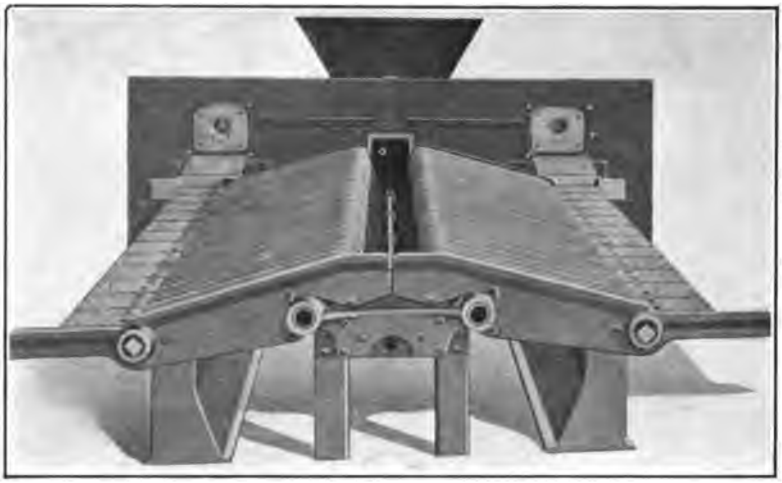


Fig. 53.—Roach Single Retort Underfeed Stoker.

Coal is conveyed from a hopper located in front by the action of a plunger operated from a steam cylinder. This plunger pushes the coal into the retort where it is distributed to the inclined side grates, which have a reciprocating motion. The fuel bed progresses over the side grates to the dump grates which are made up in sections. The ash and refuse is dumped into the ash pit, and removed from the front of the stoker or from a tunnel below.

The motion of the side grates can be adjusted so that a certain movement of the bars can be obtained.

The air distribution is controlled from a central air chamber; from this chamber air is directed to the ends of the

grate bars next to the dump grates and then travels through the bars and enters the furnace or fuel bed through the head of the bars. Air is also directed to a chamber immediately under the retort, being controlled with a valve, shutting this chamber off from the main wind box. The air taken from this so-called low-pressure air chamber and travels upwards and passes through the interstices between the grate bars.

An ignition arch is not necessary with this stoker unless the boiler and stoker application requires it. The stoker operates on forced draft the same as other stokers of this class.

CHAPTER III

COAL AND COAL-PRODUCING FIELDS OF THE UNITED STATES

COAL—DEFINITIONS

General.—According to the general meaning, coal is a solid fuel and it is something which enters combustion and produces heat.

Ash- and Moisture-Free Coal is that part of the fuel, minus ash and moisture, as neither of these take part in the combustion processes, nor do they develop heat.

Clean Coal.—Properly prepared lump coal; for example, consisting of fuel in which there is no visible ash, or, in other words, consisting of clean, black pieces accompanied by no slate or other dirt, the inference being that there are no invisible impurities with the coal.

Dirty Coal.—A fuel mixture containing a large amount of foreign matter, such as slate, fire clay, rock, etc.

Size of Coal.—This term is used to denote the sizes of coal pieces. An example of this application would be "1¼" screenings."

Kind of Coal.—This expression is used in the classification of coals, such as the following examples:

Anthracite, Semi-Anthracite, Bituminous, Semi-Bituminous, Lignite, Coking Coal, Gas Coal, Dry Coal, Moist Coal, etc.

Grade of Coal.—As an example, anthracite or bituminous are not grades of coal, but kinds. The application of the term grade is shown by the following examples: Mine run, lump, egg, nut, washed coal, washed slack, washed screenings, etc.

Caking Coal.—Some coals tend to form a solid mass when heated in a retort or furnace. This characteristic makes the coal difficult to burn by any means which does not provide an agitation to break up the cake during its processes of forma-

tion. This action is due to the peculiarity of the volatile matter but after the volatile has been driven off and the caked mass broken up, there is no further tendency for the fuel to again cake in this manner. Such coal will be known as caking coal. Coals which are most suitable for making coke possess this property.

Clinker.—Clinker is ash which has been fused. These coals containing ash having a low fusing temperature are commonly referred to as clinkering coals because when they are burned in the ordinary furnace, a considerable percentage of the ash is reduced to clinker. Those coals whose ash has a high fusing temperature are commonly referred to as non-clinkering. It is apparent, however, that if fuel is being burned economically a comparatively small amount of excess air is being introduced into the furnace and high combustion temperatures must result. The actual temperature of a particle of coal under such conditions is considerably in excess of the fusing temperature of ash even in the so-called non-clinkering coal. It therefore follows that if coal is being burned economically, a large percentage of the ash will be fused. If the method of burning coal is such that large masses of incandescent fuel in the latter stages of combustion are agitated there is a tendency to produce large clinkers, whereas if the fuel is not disturbed, smaller masses of clinker will result. Clinker becomes troublesome only when it adheres to furnace brickwork or accumulates in such quantities that it interferes with the operation of the furnace, and where clinker troubles are hereafter referred to it will be understood to refer to these large accumulations. Coal having ash of low fusing temperature will not necessarily cause clinker troubles. If the percentage of ash be low, the stoking mechanism will usually be able to accumulate and discharge the clinker from the furnace without interfering with operation. On the other hand, a coal comparatively high in ash which has a high fusing temperature can usually be handled without trouble because all of the ash will not be reduced to clinker and the accumulations will not be large enough to interfere with operation.

Coking Coal.—Some kinds of coal, when heated, give off the volatile constituents at relatively low temperatures, and

leave the carbon in a compact solid mass. This is generally known as coking coal.

USE OF COALS

Coal is used in the United States to a greater extent than any other one material, and the supply is of general importance to the industries. Coal is essential to the small enterprise as well as the public utility that develops and sells power (Fig. *54*).

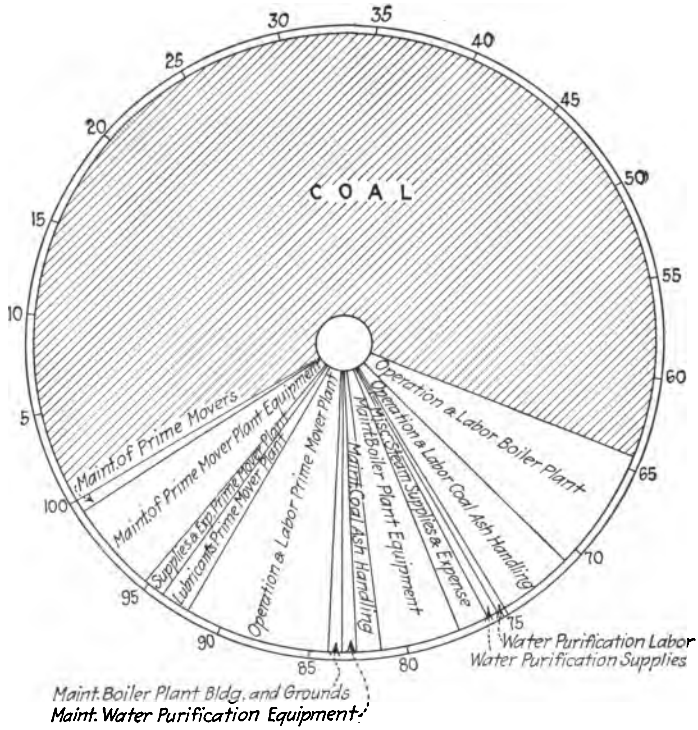


Fig. 54.—Relation of Coal Expense to Other Expenses in Public Utility Operation.

For the year of 1915 the Geological Survey obtained data which show the relative importance of the ways in which bituminous coal is used. The percentage of the total consumption in 1915 was as follows:

Industrial steam trade	33%	Exports	4%
Railroad fuel	28%	Steamship bunkers at tidewater	2%
Domestic and small steam trade	16%	Used at mines for steam and heat	2%
Manufacture of beehive coke	9%	Manufacture of coal gas	1%
Manufacture of by-product coke	4%		

Other statistics by manufacturers were computed by the Bureau of the Census for 1914. Bituminous coal was then, according to these figures, used most largely in the manufacture of the following articles (the figures represent net tons):

Coke	50,457,000	Sugar refining	875,000
Steel works and rolling mills	20,343,000	Copper smelting and refining	812,000
Brick, tile and other clay products	8,566,000	Electrical machinery, apparatus, etc	769,000
Cement	6,731,000	Furniture	751,000
Chemicals	2,667,000	Salt	714,000
Glass	2,252,000	Steam-railway cars, private builders	698,000
Petroleum refining	2,045,000	Beet sugar	682,000
Blast furnace	1,892,000	Cotton goods	3,579,000
Flour-mill and grist-mill products	1,809,000	Ice, manufactured	3,386,000
Woolen and worsted goods	1,544,000	Foundry and machine-shop products	2,913,000
Oil, cottonseed and cake	1,232,000	Slaughtering and meat packing	2,786,000
Leather, tanned, curried and finished	1,124,000	Malt liquors	2,749,000
Zinc smelting and refining	1,066,000	Lime	677,000
Rubber goods	919,000	Paving materials	665,000
Paper and wood pulp	6,268,000	Glucose and starch pottery	577,000
Gas, illuminating and heating	6,078,000	Agricultural implements	555,000
Car and general shop construction and repair by steam railways	5,486,000	Wire	523,000
Distilled liquors	909,000	Soap	515,000
Dyeing and finishing textiles	896,000	Marble and stone work	485,000
Lumber and timber products	885,000	Hosiery and knit goods	484,000
		Automobiles	464,000
		Planing-mill products, not including mills connected with saw mills	457,000
		Fertilizers	433,000

WORLD'S RESERVE

On account of the many unknown factors, an estimate on the world's coal supply is more or less speculative. According to an inquiry made in 1913, the coal reserves of the world available in the principal coal-producing countries, stand as follows:

	Short Tons
United States, including Alaska	4,231,352,000,000
Canada	1,360,535,000,000
China	1,097,436,000,000
Germany	466,665,000,000
Great Britain and Ireland	208,922,000,000
Siberia	191,667,000,000
Australia	182,510,000,000
India	87,083,000,000
Russia in Europe	66,255,000,000
Union of South Africa	61,949,000,000
Austria	59,387,000,000
Colombia	29,762,000,000
Indo-China	22,048,000,000
France	19,382,000,000
Other countries	69,369,500,000
	8,154,322,500,000

WORLD'S PRODUCTION

The latest statistics available with a degree of completeness are for the year 1914. In that year, in a world production in the neighborhood of 1,345,000,000 net tons, the United States contributed 38 per cent, Great Britain 22 per cent, and Germany 20 per cent.

In the year 1913, for which estimates are more complete, the production of all kinds of coal by the more important countries was approximately as follows:

	Net Tons		Net Tons
United States	569,000,000	France	45,000,000
Great Britain	321,000,000	Russia	35,000,000
Germany	305,000,000	Belgium	25,000,000
Austria-Hungary	59,000,000	Japan	23,000,000

COAL PRODUCTION IN THE UNITED STATES

In 1916, the United States produced over a half million tons of bituminous coal, and, as the demand for coal is now unprecedented, there is no question but what the fields will produce more than ever before. The coal produced in the United States in 1807 (the date of the earliest record) to the end of 1915 is shown in the following table:

Year	Pennsylvania Anthracite	Bituminous	Total
1807–1820	12,000	3,000	15,000
1821	1,322	....	1,322
1822	4,583	54,000	58,583
1823	8,563	60,000	68,563
1824	13,685	67,040	80,725
1825	42,988	75,000	117,988
1826	59,194	88,720	149,914
1827	78,151	94,000	172,151
1828	95,500	100,408	195,908
1829	138,086	102,000	240,086
1830	215,272	104,800	320,072
1831	217,842	120,100	337,942
1832	447,550	146,500	594,050
1833	600,907	133,750	734,657
1834	464,015	136,500	600,515
1835	690,854	134,000	824,854
1836	842,832	142,000	984,832
1837	1,071,151	182,500	1,253,651
1838	910,075	445,452	1,355,527
1839	1,008,322	552,038	1,560,360
1840	967,108	1,102,931	2,070,039
1841	1,182,441	1,108,700	2,291,141
1842	1,365,563	1,244,494	2,610,057
1843	1,556,753	1,504,121	3,060,874
1844	2,009,207	1,672,045	3,681,252
1845	2,480,032	1,829,872	4,309,904
1846	2,887,815	1,977,707	4,865,522
1847	3,551,005	1,735,062	5,286,067
1848	3,805,942	1,968,032	5,773,974
1849	3,995,334	2,453,497	6,448,831
1850	4,138,164	2,880,017	7,018,181
1851	5,481,065	3,253,460	8,734,525
1852	6,151,957	3,664,707	9,816,664
1853	6,400,426	4,169,862	10,570,288
1854	7,394,875	4,582,227	11,977,102
1855	8,141,754	4,784,919	12,926,673

Year	Pennsylvania Anthracite	Bituminous	Total
1856	8,534,779	5,012,146	13,546,925
1857	8,186,567	5,153,622	13,340,189
1858	8,426,102	5,548,376	13,974,478
1859	9,619,771	6,013,404	15,633,175
1860	8,115,842	6,494,200	14,610,042
1861	9,799,654	6,688,358	16,488,012
1862	9,695,110	7,790,725	17,485,835
1863	11,785,320	9,533,742	21,319,062
1864	12,538,649	11,066,474	23,605,123
1865	11,891,746	11,900,427	23,792,173
1866	15,651,183	13,352,400	29,003,583
1867	16,002,109	14,722,313	30,724,422
1868	17,003,405	15,858,555	32,861,960
1869	17,083,134	15,821,226	32,904,360
1870	15,664,275	17,371,305	33,035,580
1871	19,342,057	27,543,023	46,885,080
1872	24,233,166	27,220,233	51,453,399
1873	26,152,837	31,449,643	57,602,480
1874	24,818,790	27,787,130	52,605,920
1875	22,485,766	29,862,554	52,348,320
1876	22,793,245	30,486,755	53,280,000
1877	25,660,316	34,841,444	60,501,760
1878	21,689,682	36,245,918	57,935,600
1879	30,207,793	37,898,006	68,105,799
1880	28,649,812	42,831,758	71,481,570
1881	31,920,018	53,961,012	85,881,030
1882	35,121,256	68,429,933	103,551,189
1883	38,456,845	77,250,680	115,707,525
1884	37,156,847	82,998,704	120,155,551
1885	38,335,974	72,824,321	111,160,295
1886	39,035,446	74,644,981	113,680,427
1887	42,088,197	88,562,314	130,650,511
1888	46,619,564	102,040,093	148,659,657
1889	45,546,970	95,682,543	141,229,513
1890	46,468,641	111,302,322	157,770,963

Year	Pennsylvania Anthracite	Bituminous	Total
1891	50,665,431	117,901,238	168,566,669
1892	52,472,504	126,856,567	179,329,071
1893	53,967,543	128,385,231	182,352,774
1894	51,921,121	118,820,405	170,741,526
1895	57,999,337	135,118,193	193,117,530
1896	54,346,081	137,640,276	191,986,357
1897	52,611,680	147,617,519	200,229,199
1898	53,382,644	166,593,623	219,976,267
1899	60,418,005	193,323,187	253,741,192
1900	57,367,915	212,316,112	269,684,027
1901	67,471,667	225,828,149	293,299,816
1902	41,373,595	260,216,844	301,590,439
1903	74,607,068	282,749,348	357,356,416
1904	73,156,709	278,659,689	351,816,398
1905	77,659,850	315,062,785	392,722,635
1906	71,282,411	342,874,867	414,157,278
1907	85,604,312	394,759,112	480,363,424
1908	83,268,754	332,573,944	415,842,698
1909	81,070,359	379,744,257	460,814,616
1910	84,485,236	417,111,142	501,596,378
1911	90,464,067	405,907,059	496,371,126
1912	84,361,598	450,104,982	534,466,580
1913	91,524,922	478,435,297	569,960,219
1914	90,821,507	422,703,970	513,525,477
1915	88,995,061	442,624,426	531,619,487
	2,626,512,578	8,262,792,323	10,889,304,901

COAL PRODUCING STATES

Coal is produced in thirty states, but almost eighty (80%) per cent. is produced west of the Mississippi river. The relative importance of the states was expressed by the Geological Survey in percentage of all coal produced (bituminous and anthracite) as follows, for 1915:

Pennsylvania:	
Anthracite	16.8%
Bituminous	29.7%
West Virginia	14.5%
Illinois	11.1%
Ohio	4.2%
Kentucky	4.0%
Indiana	3.2%
Alabama	2.8%
Colorado	1.6%
Virginia	1.5%
Maryland	.8%
Oklahoma	.8%
Missouri	.8%
New Mexico	.7%
Utah	.6%
Washington	.6%
Montana	.5%
Texas	.4%
Arkansas	.3%
Michigan	.2%
Iowa	1.4%
Kansas	1.3%
Wyoming	1.2%
North Dakota	.1%
Georgia, Oregon, California, Idaho, Nevada, South Dakota	.1%

COMPOSITION OF COALS

To some extent, the analysis of a coal will give some indication of how successfully it can be handled on a grate or stoker. These analyses can be made with proper facilities, and are not too technical for boiler-room work. The two analyses generally used are the Proximate analysis and Ultimate analysis.

Proximate Analysis.—The proximate analysis of coal determines the moisture, volatile matter, fixed carbon, percentage of ash, and sulphur (separately determined). The fixed carbon is the carbon remaining after distillation. Volatile matter is the total combustible, less the carbon contents, and includes hydric carbons, etc. Ash is the residue remaining after the moisture and volatile contents have been driven off and the carbon consumed. Moisture is that percentage of the weight of the coal when dried at a given temperature.

Ultimate Analysis.—The ultimate analysis is a more complicated chemical analysis giving the percentages of carbon (C), hydrogen (H), nitrogen (N), Sulphur (S), and ash (A). This analysis is used, and is necessary for making the heat balance on any given boiler test. The ultimate analysis does not distinguish between the carbon and hydrogen derived from the combustible matter of coal.

Heating Value.—The heating value, sometimes called the calorific value of coal, is the number of units of heat liberated by the perfect combustion of a unit weight of the coal. The British Thermal Unit (B.T.U.) is used to designate the heating value, and is the quantity of heat required to raise the temperature of one pound of water 1° F. A bomb calorimeter, many of which are on the market, is used to determine the heating value of coal, and can easily be used in connection with boiler-room equipment.

Heating Value from Analysis.—A number of equations have been derived to give the heating value of coal from the analysis. The one most commonly used is DuLong's formula, which is as follows:

$$\text{B.T.U. per lb. of coal} = 14{,}544\,C + 62{,}028\left(H - \frac{O}{8}\right) + 4050\,S.$$

C, H, O and S are the percentages of carbon, hydrogen, oxygen and sulphur, respectively, in the combustible.

For western coals, DuLong's formula gives heating values a little too low, but for eastern coals, is sufficiently close for estimating purposes.

CLASSIFICATION OF COALS

U. S. Geological Survey.—Coals can be classified in many different ways, namely, according to the chemical composition, the ratio of volatile and carbon, location of mines, etc. The United States Geological Survey method of classifying coals is part chemical and part physical, the same being as follows:

Anthracite is generally defined as hard coal, most of it being mined in Eastern Pennsylvania. Small areas of anthracite occur in the West. Anthracite is an almost ideal domestic fuel, but largely on account of its low heating power, it is not an

economical fuel for steam raising or for use in general manufacturing.

Semi-Anthracite is also a hard coal, but it is not so hard as true anthracite. It is high in fixed carbon, but not so high as anthracite. The change of ordinary soft coal to semi-anthracite is due to the same causes that produced anthracite, except that the process has not been carried so far in semi-anthracite. There is very little semi-anthracite in this country, so it is only a small factor in the coal trade. Such semi-anthracite as is mined reaches the consumer generally under the name "anthracite."

Semi-Bituminous.—The name "semi-bituminous" is exceedingly unfortunate, as literally it implies that this coal is half the rank of bituminous, whereas, it is applied to a kind of coal that is of higher rank than bituminous—really super-bituminous. Its relatively high percentage of fixed carbon makes it nearly smokeless when it is burned properly, and consequently, most of these coals go into the market as "smokeless coals." The best coal of this type has a heating value greater than that of any of the other ranks, and is, consequently, best adapted to raising steam and to general manufacturing that requires a high degree of heat. It is regarded as the best coal for steamship and especially for naval use, as it is nearly smokeless and requires less bunker space per unit of heat than other coals. The coal is generally minutely jointed and is, therefore, tender and friable. In fact, it is so friable that, in mining, a large percentage of fine coal is produced, and in transportation, many of the lumps are broken to pieces, so that by the time it reaches the consumer, especially if it has been transshipped, it is generally in small pieces. This fineness is, by many, regarded as detrimental because the public is accustomed to lump coal which will stand transportation without crushing, but when this coal is used with mechanical stokers and with a grate adapted to its use, the fineness of the coal is not disadvantageous. The great bulk of this kind of coal is in the eastern fields, but some is found in the West.

Bituminous.—The term "bituminous," as generally understood, is applied to a group of coals in which the volatile matter and the fixed carbon are nearly equal; but this criterion cannot

be used without qualification, for the same statement might be made of sub-bituminous coal and lignite. As noted before, the distinguishing feature which serves to separate bituminous coal from coals of lower rank is the manner in which it is affected by weathering. Bituminous coal is only slightly affected chemically by weathering unless it is exposed for many years, and then, although it consists of small particles, each particle is a prismatic fragment, whereas coals of lower rank break into thin plates parallel with the bedding.

Sub-Bituminous.—The term "Sub-bituminous" is adopted by the Geological Survey for what has generally been called "black lignite," a term that is objectionable because the coal is not lignite in the sense of being distinctly woody. Sub-bituminous coal is generally distinguishable from lignite by its black color and its apparent freedom from distinctly woody texture and structure, and from bituminous coal by its loss of moisture and the consequent breaking down or "slacking" that it undergoes when subjected to alternate wetting and drying. As the percentage of moisture is an important matter in buying and shipping coal, and as the slacking on exposure to the weather makes it necessary to ship in box cars and to guard carefully against spontaneous ignition, there is a great commercial difference in these two kinds of coal which the Geological Survey has recognized by putting them in different ranks. Despite the many drawbacks in the shipment and use of sub-bituminous coal, it has found a ready market in much of the western country, because it is a very clean domestic fuel and ignites with little difficulty.

Sub-bituminous coals differ considerably in chemical composition and in physical appearance. Some are banded like much of the bituminous coal, and some are essentially cannel in physical and chemical make-up. In general, the younger coals of the West contain a smaller percentage of sulphur than the older coals of the East, and some of them are high in volatile matter.

Lignite.—The term "lignite," as used by the Geological Survey, is restricted to those coals which are distinctly brown and either markedly woody or claylike in their appearance. They are intermediate in quality and in development between

peat and sub-bituminous coal. As the moisture of lignite as it comes from the mine generally ranges from 30 to 40 per cent, its heating value is low, and the consumer cannot afford to pay freight for any great distance on so much water. Also, it parts with much of this moisture very readily when exposed to the weather and so falls to pieces or slacks much more readily and completely than sub-bituminous coal. On this account, it is more likely to ignite spontaneously and must be handled even more carefully than sub-bituminous coal and stored in a place where it will not be exposed to alternate wetting and drying. Lignite is mainly marketed near the mine, as a domestic fuel, but at a few places in North Dakota and Texas, it is shipped to nearby towns and used for general manufacturing purposes.

Lignite can be manufactured into hard briquets, which make an excellent fuel, but so far, the cost of manufacture has been prohibitive.

Wm. Kent Classification.—A classification of American coals, based on the proximate and ultimate analyses and heating values of 155 coals from different States selected from the analyses of over 3,000 coals published in Bulletin 22 of the U. S. Bureau of Mines, is as follows:

CLASSIFICATION AND HEATING VALUE OF COALS

	Volatile Matter, Per Cent of Combustible	Oxygen in Combustible Per Cent	Moisture in Air Dry Coal Free from Ash, Per Cent	B.T.U. per Pound Combustible	B.T.U. per Pound Coal Air Dry Ash Free
I. Anthracite.....	Less than 10	1 to 4 10	Less than 1.8	14,800 to 15,400	14,600 to 15,400
II. Semi-anthracite.	10 to 15	1 to 5	Less than 1.8	15,400 to 15,500	15,200 to 15,500
III. Semi-bituminous	15 to 30	1 to 6	Less than 1.8	15,400 to 16,050	15,300 to 16,000
IV. Cannel*.......	45 to 60	5 to 8	Less than 1.8	15,700 to 16,200	15,500 to 16,050
V. Bituminous, high grade.....	30 to 45	5 to 14	1 to 4	14,800 to 15,600	14,350 to 15,500
VI. Bituminous, medium grade....	32 to 50	6 to 14	2.5 to 6.5	13,800 to 15,100	13,400 to 14,400
VII. Bituminous, low grade..........	32 to 50	7 to 14	5 to 12	12,400 to 14,600	11,300 to 13,400
VIII. Sub-bituminous and lignite.....	27 to 60	10 to 33	7 to 26	9,600 to 13,250	7,400 to 11,650

* Eastern cannel. The Utah cannel is much lower in heating value.

Classes I, II and III are the same as in earlier classifications, the semi-bituminous coals containing between 15 and 30 per cent of volatile matter in the combustible. Classes V, VI and VII have heretofore been considered as a single class, but they vary greatly in heating value and in the amount of moisture remaining in air-dried coal, which is used as the basis of the sub-division into three classes. Class VIII includes the two classes sub-bituminous and lignite, of the U. S. Geological Survey, which are differentiated one from the other by color, texture and disintegration by weathering, but not by heating value or by analysis.

COMPOSITION OF TYPICAL COALS

Trade Names of Coals and Location	Proximate Analysis					B.T.U. value as Fired
	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	
Eastern Coals						
New River, W. Va.	2.14	21.73	71.56	4.57	.80	14,690
Pocahontas, W. Va.	2.09	14.70	76.75	6.46	.71	14,520
Cabin Creek, W. Va.	2.00	26.20	66.50	5.30	1.20	13,995
Georges Creek, Md.	1.45	19.25	70.09	9.21	1.42	14,451
Kittanning run-of-mine, Pa.	.56	16.71	76.22	6.51	1.10	14,279
Pittsburgh Coals						
Pittsburgh run-of-mine, Pa.	1.61	32.19	55.94	10.26	1.33	13,561
Youghiogheny run-of-mine, Pa.	1.37	31.70	57.00	9.93	.80	13,317
Fairmont run-of-mine, W. Va.	1.76	33.36	53.62	11.26	2.91	12,800
Hocking Valley lump, Ohio	7.24	30.47	51.41	10.88	1.26	11,777
Buffalo, Rochester and Pittsburgh slack, Pa.	6.02	30.29	52.34	11.35	1.85	12,460
Shawmut slack, Pa.	.69	31.76	57.78	9.77	2.02	13,410
Reynoldsville slack, Pa.	1.12	29.64	58.74	10.50	1.10	13,564
Middle Western Coals						
Carterville mine-run, Ill.	9.04	32.63	47.01	11.32	2.80	11,650
Seeleyville mine-run, Ind.	7.12	39.78	43.70	9.40	1.81	11,830
Hocking Valley mine-run, Ohio	7.92	35.98	46.93	9.17	4.90	12,258
Luzerne mine-run, Ky.	7.90	30.97	47.75	13.38	3.62	11,507
Saginaw mine-run, Mich.	11.90	31.50	49.80	6.80	1.20	11,780
Eastern mine-run, Tenn.	1.40	35.12	49.50	13.98	3.10	13,020
Missouri City coal, Mo.	12.10	36.30	42.90	8.70	3.9	11,450
Sub-Bituminous and Lignites						
Denver mine-run, Colo.	18.80	30.50	40.50	10.20	.60	9,650
Lehigh mine-run, N. D.	40.50	26.30	27.00	6.20	.80	10,121
Houston lignite, Texas	28.90	35.90	27.30	7.90	.50	8,000
Monarch mine, Wyo.	22.60	32.50	40.40	4.50	1.40	12,316
New Castle mine, Wash.	12.10	36.80	40.70	10.40	.30	12,590
Coos Bay mine, Oregon	18.00	31.80	39.70	10.50	2.20	8,910
New Market mine, Iowa	14.48	33.51	34.60	17.41	4.50	9,572

Commercial Classification.—The classification of coals, as adopted by the United States Geological Survey, seems to suit the particular conditions under which the Survey operates, but combustion engineers and mechanical stoker manufacturers classify coals more according to their action to coke or fuse when burned on a grate. The following classification is generally used in connection with stoker work:

Eastern Bituminous Coal.—This embraces the bituminous coals of Virginia, Eastern Pennsylvania, West Virginia and Maryland. The coal is a caking coal, low volatile, low ash, high fixed carbon with about the following proximate analysis:

Moisture	1%	to	5%
Volatile Matter	16%	to	22%
Fixed Carbon	68%	to	77%
Ash	3%	to	10%
Sulphur	.8%	to	1.5%
B.T.U.	14,000	to	15,000

Pittsburgh Coal.—This coal embraces the bituminous coals of Western Pennsylvania, Eastern Ohio, Eastern Kentucky and part of West Virginia. This is a coking coal, high in volatile matter, with about the following proximate analysis:

Moisture	3%	to	8%
Volatile Matter	32%	to	38%
Fixed Carbon	56%	to	60%
Ash	9%	to	12%
Sulphur	1.5%	to	3%
B.T.U.	13,500	to	14,200

Middle West Coal.—Most of the Middle West coals, coming from Illinois, Michigan and Indiana, are free burning and of high ash content. These coals have about the following proximate analysis:

Moisture	8%	to	14%
Volatile Matter	28%	to	35%
Fixed Carbon	38%	to	53%
Ash	8%	to	20%
Sulphur	3%	to	4%
B.T.U.	11,300	to	12,500

Eastern Kentucky, Tennessee and Alabama Coal.—Most of the coal from this group is free burning and relatively high in heating value. They have about the following proximate analysis:

Moisture	5%	to	10%
Volatile Matter	30%	to	37%
Fixed Carbon	50%	to	60%
Ash	5%	to	15%
B.T.U.	13,000	to	13,500

Texas, Oklahoma and Arkansas Coal.—Many different kinds of coals are found in these states, ranging from semi-anthracite to lignites, these coals having about the following proximate analysis:

(*a*) *Semi-anthracite*—			
Volatile Matter	10%	to	16%
Fixed Carbon	70%	to	77%
Ash	8%	to	18%
B.T.U.	13,500	to	14,000
(*b*) Bituminous—			
Volatile Matter	30%	to	35%
Fixed Carbon	30%	to	40%
Ash	10%	to	20%
B.T.U.	11,500	to	12,500
(*c*) Lignite—			
Moisture	20%	to	35%
Volatile Matter	30%	to	40%
Fixed Carbon	30%	to	35%
Ash	10%	to	15%
B.T.U.	7000	to	9000

Colorado Coals.—The coals produced and used in Colorado range from anthracite to bituminous and lignite. In the western part of the state, the coal is high volatile and free burning. The coal in the southern part of the state represents very much the Pittsburgh coals inasmuch as it is a highly coking coal. In the northwestern part of the state, some anthracite coal is used.

What is generally termed "Denver Lignite" (coals of lignitic nature coming from the vicinity of Denver) is very high in

moisture and slacks when heated, and has about the following proximate analysis:

Denver Lignite—

Moisture	18%	to	20%
Volatile Matter	30%	to	36%
Fixed Carbon	36%	to	44%
B.T.U.	9000	to	9600
Sulphur	2%	to	3%
Ash	6%	to	8%

Washington, Wyoming and Montana Coal.—Some of the coals from Washington, especially Roslyn, are bituminous coals of high grade, the same having the following proximate analysis:

Roslyn, Wash.:		Rock Springs, Wyo.:		Nelson, Mont.:	
Moisture	3.77%	Moisture	9.8%	Moisture	3.60%
Vol. mat.	37.69%	Vol. mat.	34.3%	Vol. mat.	28.52%
F. C.	47.05%	F. C.	52.5%	F. C.	46.41%
Ash	11.49%	Ash	3.4%	Ash	21.47%
Sulphur	.47%	Sulphur	1.0%	Sulphur	
B.T.U.	12,767	B.T.U.	12200	B.T.U.	10,447

North Dakota Lignite.—This coal is of lignitic nature, containing a high percentage of moisture and a low heating value, and very little, if any, sulphur. An average proximate analysis of this coal from one of the best mines is as follows:

Moisture	30.6%
Volatile matter	31.9%
Fixed carbon	32.2%
Ash	5.3%
B.T.U.	8058

Coke Breeze.—Coke breeze is the refuse that is taken from coke ovens whenever they are drawn. For some time, this fuel had no value but is now being used successfully for steam purposes. There are two kinds of coke breeze, one coming from beehive, and the other from by-product coke ovens. Some is what is called 48-hour drawn, and others 72-hour drawn, and there is quite a difference between the two fuels. This fuel has the following proximate analysis:

	48-hour drawn	72-hour drawn
Moisture	3.51	5.24
Volatile matter	12.58	6.07
Fixed carbon	58.66	62.13
Ash	28.76	31.80
Sulphur	.083	1.02
B.T.U	11,017	10,323

The average coke breeze contains from 25% to 35% sand, sulphur and fire-clay which tend to make clinkers when the fuel is heated.

Anthracite Culm.—Most of the anthracite coal produced is used for domestic purposes, but the fine anthracite screenings have, for some years, been a waste product and thrown out in great piles in the anthracite mining regions. These screenings have been used successfully on some types of stokers, and have also been used when mixed with bituminous coal. The sizes most generally and successfully used are Nos. 2 and 3 Buckwheat, No. 2 Buckwheat having about the following proximate analysis:

Ash	21%
Moisture	8%
B.T.U	10,500

The screening sizes used generally for anthracite coal are as follows:

No. 1	buckwheat	through	$\frac{9}{16}''$	over	$\frac{5}{16}''$
No. 2	"	"	$\frac{5}{16}''$	"	$\frac{3}{16}''$
No. 3	"	"	$\frac{3}{16}''$	"	$\frac{3}{32}''$
No. 4	"	"	$\frac{3}{32}''$	"	$\frac{3}{64}''$

Bone Coal.—The refuse from coal mining consisting of slate and bone coal was, for many years, thrown out in great piles and considered a waste product. This refuse, however, had been used in connection with stoker-fired furnaces. It is very high in ash and low in heat value with about the following proximate analysis:

Moisture	3% to 6%
Volatile matter	15% to 20%
Fixed carbon	20% to 25%
Ash	25% to 50%
Sulphur	1% to 2%
B.T.U	3000 to 6000

TABLE II

CHANGES IN WEIGHT OR VOLUME OF COAL BY WETTING AND SHAKING

	Dec. 13, 1915	Dec. 13, 1915	Dec. 16, 1915	Dec. 16, 1915	Jan. 20, 1916	Jan. 21, 1916	Jan. 22, 1916	Jan. 24, 1916	Jan. 25, 1916
	Nut	Slack	Nut	Slack *					
Weight of 8 cubic feet of coal in original condition (pounds)	351.5	393	363	372	388				
Weight of 8 cubic feet of same coal after wetting (pounds)	364.5	419	370	393	416	392	388	386	388
Settling when shaken (inches)	......	......	......	......	1	1½	1½	2	1½
Total weight of original 8 cubic feet of coal, moist condition (pounds)	364.5	426	371	408	421	396	391	389	388
Moisture in coal in original condition (per cent)	1.5†	2.5†	1.85	2.13	3.26				
Moisture in wet coal (per cent)	5.0	9.6	3.97	10.76	10.8	5.20	3.99	3.50	3.26
Weight of coal per cubic foot in original condition (pounds)	44	49.1	45.4	46.5	48.5				
Weight of moist coal per cubic foot (pounds)	45.6	52.4	46.3	49.1	52.0	49.0	48.5	48.25	48.5
Increase in weight of unit volume of coal through wetting (per cent)‡	3.64	6.72	1.98	7.74	7.22	1.03	0	0.51§	0
Volume of original 8 cubic feet of coal in moist condition (cubic feet)	8.00	8.134	8.022	8.306	8.10	8.082	8.062	8.062	8.00
Increase in volume from increase in moisture (per cent)	0	1.67	0.27	3.8	1.24	1.02	0.77	0.78	0
Reduction in volume from shaking (per cent)	......	......	......	......	4.2	6.25	6.25	8.34	6.25

* Determinations of Jan. 20–25, 1916, were made with the same sample of coal. This coal was wet on the 20th, and exposed to the atmosphere.

† Moisture assumed.

‡ Volume obtained by shoveling the coal loosely into a box measuring 2 feet by 2 feet by 2 feet and leveling off with a straightedge.

§ Decrease.

COALS USED BY POWER PLANTS THROUGHOUT THE UNITED STATES

As the largest expense in connection with central station operation is the cost of coal (see Fig. 54), naturally considerable attention has been given to the kind of coal used and method of firing. The following table gives some of the large central stations of the United States, and the name and proximate analysis of the coal generally used:

Name of Plant	Name of Coal	Coal Analysis					
		Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.T.U.
Alabama Power Company, Birmingham, Ala	Pratt run-of-mine	4	31	56	10	1.5	13,500 dry
American Gas & El. Co., Wheeling, Va	West Virginia	4.1	36.6	53.3	6	2.1	13,400 dry
American Locomotive Wks., Schenectady, N. Y	Pittsburgh	....	35.0	59.0	6.0	1	14,000 dry
Appalachian Power Co., Glen Lynn, Va	Pocahontas	2.0	19.0	71.0	8.0	1.5	14,000 dry
Arkansas Valley El. Ry. & Light Co., Cañon City, Colo	Colorado	6.83	36.19	47.03	9.95	.68	10,919 as fired
" " " " " " " " " "	Chandler slack, Colo	8.22	36.40	54.00	9.60	....	12,287 as fired
" " " " " " " " " "	Radiant slack, "	8.25	32.10	46.15	21.75	....	10,641 as fired
Ashville El. Lt. & Pr. Co., Ashville, N. C	West Virginia, "	3	41	51	5.0	1.5	13,500 dry
Atlas Power Company, Perrysville, Md	West Virginia	4.0	20.0	68.0	8.0	1.5	13,500 dry
B. F. Goodrich Co., Akron, Ohio	W. Penn., W. Va. and Ohio	4.0	31.7	51.11	13.19	1.76	12,155 dry
Bridgeman-Russell Co., Duluth, Minn., Grand Forks, N. D.	Pittsburgh	....	....	....	....	....	13,500 dry
Buffalo Gen. Elec. Co., Buffalo, N. Y	Pittsburgh	3	34	44	9.0	2.0	13,500 dry
Cadillac Motor Car. Co., Detroit, Mich	Pittsburgh	....	....	....	....	....	14,000 dry
Cambria Steel (Elec. Plt.), Johnstown, Pa	Pittsburgh mine-run slack	4.0	17.28	67.2	11.52	2.58	12,000 dry
Canton Electric Co., Canton, Ohio	Ohio slack	3.9	43.1	43.9	9.1	1.5	13,000 dry
Cheyenne Lt. & Pr. Co., Cheyenne, Wyo	Rock Springs, Wyo	9.8	34.3	52.5	3.4	1.0	12,260 dry
City of Cleveland, Ohio	Pittsburgh	....	....	....	12 or less	....	13,000 dry
City of Edmonton, Canada	Alberta lignite	25.0	28.0	29.0	18.0	....	7,800 as fired
City of Kansas City, Kansas City, Kans	Bituminous slack	6.0	35.0	47.0	18.0	....	10,100 dry
City of Miles City, Mont	Round up coal mining	9.70	46.70	30.15	13.45	0.43	12,064 dry
	Round up slack or pea-run coal	....	....	....	....	....	10,894 as fired

COALS USED BY POWER PLANTS THROUGHOUT THE UNITED STATES—*Continued*

Name of Plant	Name of Coal	Coal Analysis					
		Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.T.U.
City of Richmond, Ind.	Indiana nut and slack	14.0	35.0	45.0	18.0	3.0	11,000 as fired
Cleveland Elec. Illg. Co., Cleveland, Ohio	Coshocton Co., Ohio	4.5	38.7	50.8	6.0	3.0	12,800 dry
Colorado Fuel & Iron Co., Rouse Mine, Colo.	Rouse slack	6.24	26.4	50.62	16.78	0.81	13,000 dry
Commonwealth Edison Co., Chicago, Ill.	LaSalle, Ill.	13.9	37.3	38.5	10.3	3.5	10 000 as fired
Consumers Power Co., St. Paul, Minn.	Hocking Valley, Ill.	7.0	30.81	56.48	11.03	1.70	13,400 dry
		10.0	32.59	43.49	20.44	3.46	11,200 dry
Consumers Power Co., " "	West Virginia bituminous	3.0	35.0	58.5	6.5	1.25	14,000 dry
Conn. Lt. & Pr. Co., Waterbury, Conn.	Eastern	3.0	20.0	....	10.0	2.0	13,000 dry
	Winkle No. 3, Ill.	12.0	27.23	36.79	23.68	....	9,612 as fired
Central Ill. Lt. Co., Peoria, Ill.	Winkle No. 8, Ill.	15.3	25.0	35.2	24.5	....	9,522 as fired
	Livingston No. 6, Ill.	14.5	29.0	39.1	17.4	....	11,112 as fired
Counties Gas & Elec. Co., Norristown, Pa.	Penna. bituminous	5.0	17.0	67.0	10.0	....	13,500 dry
Counties Gas & Elec. Co., Norristown, Pa.	Ash fusion temp., 2410° F.) (Ash color terra cotta)	2.64	17.43	71.96	7.97	1.11	14,012 dry
Denver Gas & Elec. Co., Denver, Colo.	Colorado	1.7	35.85	39.0	5.37	0.42	12,000 dry
Detroit Edison Co., Detroit, Mich.	West Virginia	2.0	32.0	58.0	7.0	0.1	13,800 dry
Duluth & Iron Range R., Two Harbors, Minn.	Pittsburgh slack	2.97	40.15	53.55	6.3	2.2	13,982 dry
Dupont Engr. Co., Nashville, Tenn.	Alabama	9.0	40.0	48.5	13.5	3.4	12,500 dry
Duquesne Light Co., Pittsburgh, Pa.	Pittsburgh	3.50	34.07	51.23	11.20	3.3	12,803 dry
		1.90	32.47	54.84	10.79	1.3	13,533 dry
Eastern Conn. Pr. Co., Montville, Conn.	Eastern bituminous	2.0	19.0	71.0	3.0	1.5	13,000 dry
Edison Elec. Illg. Co., Boston, Mass.	New River	3.25	20.75	73.5	5.75	1.05	14,000 dry
Electric Lt. & Pr. Co., York, Pa.	"Valley" smokeless bitum.	....	....	....	10.0	....	14,000 dry
Elmira W. L. & Rwy. Co., Elmira, N. Y.	Pittsburgh	3.0	30.0	58.0	9.0	1.5	13,500 dry
Endicott-Johnson Co., Johnson City, N. Y.	Pittsburgh bituminous	4.0	27.32	56.0	9.12	1.5	13,000 dry
Ft. Wayne & N. Ind. Trac. Co., Ft. Wayne, Ind.	Indiana screenings	....	....	....	15.0	....	11,500 dry

COALS USED BY POWER PLANTS THROUGHOUT THE UNITED STATES—*Continued*

Name of Plant	Name of Coal	Coal Analysis					
		Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.T.U.
Ft. Worth Elec. Lt. & Pr., Ft. Worth, Texas	Indiana and Ohio screenings	....	....	....	15.0	....	11,500 dry
Goodyear Tire & Rubber, Akron, Ohio	Pittsburgh slack	7.0	34.0	48.5	9.5	....	13,750 dry
Imperial Steel Wks., Japan	Japanese	....	....	....	....	....	10,400 dry
Interboro Rapid Transit, New York City	Semi-bitum. run-of-mine	....	11–22	70–78	4–11	1–2.2	13,800 dry
							15,000 dry
Interstate Lt. & Pr., Galena, Ill.	Illinois "A"	8.0	35.0	45.0	12.0	1.20	12,300 dry
	Screenings "B"	10.0	32.59	43.49	20.44	3.48	11,200 dry
Kansas City Rwy. Co., Kansas City, Mo.	Cherokee Co., Kansas coal	6.16	29.40	46.90	17.54	3.0	9,564 as fired
Kiushu Elec. Rwy. Co., Japan	....	....	....	....	....	....	10,000 dry
LaBelle Iron Wks., Steubenville, Ohio	Pittsburgh and Ohio	4.0	30.0	55.0	11.0	1.5	13,000 dry
Lehigh Valley Transit, Allentown, Pa.	Pennsylvania bituminous	2.0	19.0	71.0	8.0	1.5	13,000 dry
Little Rock Rwy. & Elec., Little Rock, Ark.	Huntington, Hartford and Benning, Ark., and Calhoun, Okla.	4.0	25.0	68.0	8.0	....	12,000 dry
Louisville Gas & Elec., Louisville, Ky.	Western Kentucky	3.90	39.83	38.37	13.42	4.86	12,700 dry
Mansfield Elec. Lt. & Pr. Co., Mansfield, Ohio	Ohio and West Virginia	....	....	....	....	....	11,000 dry
Massillon Elec. & Gas, Massillon, Ohio	Goshen	5.43	37.82	43.78	12.97	4.27	12,080 dry
Merchants Central Htg. Co., Spokane, Wash.	Roslyn, Wash.	3.19	37.40	47.85	12.56	0.31	12,587 dry
Merchants Ht. & Lt. Co., Indianapolis, Ind.	Indiana block	5.23	40.27	43.89	15.84	3.99	12,053 dry
Minneapolis Gen. El. Co., Minneapolis, Minn.	Illinois	7.0	30.81	56.48	11.03	1.70	13 400 dry
	Youghiogheny screenings	10.0	32.59	43.49	20.44	3.46	11,200 as fired
Michigan Power Co., Lansing, Mich.	Southern Illinois	11.0	31.0	41.0	17.0	3.5	11,500 dry
Minn. State Sanatorium, Minneapolis (plant Walker, Minn)	....	10.0	35.0	46.0	12.0	1.5	12,000 dry
Minnesota Steel Co., Minneapolis, Minn.	Youghiogheny	2.00	31.0	57.0	10.0	....	13,000 dry

COALS USED BY POWER PLANTS THROUGHOUT THE UNITED STATES—*Continued*

Name of Plant	Name of Coal	Coal Analysis					
		Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.T.U.
Missoula Lt. & Pr. Co., Missoula, Mont.	"Pea slack," Roundup coal mining, Roundup, Mont.	9.70	46.70	46.70	30.15	0.43	10,894 dry
Mobile Elec. Co., Mobile, Ala.	Blocton, No. 10	4.0	34.0	51.0	14.0	1.85	12,500 dry
Metropolitan Edison, Reading, Pa.	Crushed run-of-mine from Lost Creek vein, Harrison City, W. Va.	1.0	25.0	62.0	12.0	....	13,521 dry
National Tube Co., McKeesport, Pa.	Crushed bituminous	2.5	33.65	57.2	9.15	1.71	13,500 dry
N. J. Power & Lt. Co., Dover, N. J.	Bitum. and anthr. rice	2.0	31.0	59.0	10.0	2.0	14,600 dry
N. Y. Edison Co., New York City	Pennsylvania	3.0	16.0	71.0	10.0	....	13,369 dry
New Orleans Elec. Rwy. Lt. & Pr. Co., New Orleans, La.	Carona, Townley mines	2.55	31.66	47.95	17.84	1.38	11,787 dry
Norfolk & Western, Bluestone, W. Va.	West Virginia	....	16.86	62.44	20.70	....	12,245 dry
North Adams Gas Lt., Mass.	Eastern bituminous	1.0	22.0	70.0	7.0	1.0	14,200 dry
Ohio Lt. & Pr. Co., Newark, Ohio	Pittsburgh	3.0	32.0	56.0	9.0	1.5	14,200 dry
Okla. Rwy. Co., Okla. City, Okla.	Mined in Arkansas	....	21.4	62.2	16.4	....	13,000 dry
Oliver Iron Mng. Co., Duluth, Minn.	Pittsburgh slack	3.70	37.44	47.75	16.81	2.84	11,512 as fired
	Illinois slack	17.78	32.0	45.0	23.0	2.36	9,105 as fired
Osaka Elec. Lt. Co., Japan	....	5.0	35.5	40.0	18.3	1.2	10,400 as fired
Oshkosh Gas Lt. Co., Oshkosh, Wis.	Youghiogheny screenings	....	....	....	....	....	13,000 dry
Penn. Public Service Corp., Rockwood, Pa.	Pittsburgh nut and slack	1.25	18.0	68.0	12.75	2.5	13,000 dry
Penn. Public Service, Johnstown, Pa.	Penna. bituminous	0.25	18.0	71.75	10.0	2.0	13,750 dry
Penna. Utilities Co., Easton, Pa.	Penna. run-of-mine	2.0	31.0	62.0	10.0	2.0	14,600 dry
Pittsburgh & W. Va. Rwys. Co., Pittsburgh, Pa.	Pittsburgh crushed	3.0	32.0	56.0	9.0	1.5	13,500 dry
Public Service Elec., Jersey City, N. J.	Eastern	3.5	24.0	64.0	11.5	2.0	13,500 dry
Racine Auto Tire Co., Racine, Wis.	Illinois screenings	....	....	....	....	....	12,000 dry
Reading Transit & Lt. Co., Metropolitan Edison Co., Reading, Pa.	Penna	....	....	....	Not over 10	....	14,000 dry

COALS USED BY POWER PLANTS THROUGHOUT THE UNITED STATES—*Continued*

Name of Plant	Name of Coal	Coal Analysis					
		Moisture	Volatile	Fixed Carbon	Ash	Sulphur	B.T.U.
Roanoke Ry. & El. Co., Roanoke, Va	Pocahontas	3.4	22.5	66.1	8.0	....	14,200 dry
Rochester Ry. & Lt. Co., Rochester, N. Y	Pittsburgh slack	3.0	32.0	56.0	9.0	1.5	13,000 dry
St. Paul Gas Lt. Co, St. Paul, Minn	Pittsburgh, No. 1	3.0	32.0	56.0	9.0	1.5	13,500 dry
	Illinois, No. 2	....	....	....	....	....	9,000 as fired
Springfield Lt. Ht. Pr., Springfield, Ohio	Logan City	3.3	33.3	58.4	5.0	0.7	14,050 dry
Three Forks Portland Cement Company	Red Lodge, Mont	6.02	35.0	44.89	13.0	0.79	11,580 dry
Tug River Pr. Co., Welch, W. Va	West Virginia	....	....	55.0	11.0	0.6	12,000 dry
Twin City Rapid Transit Co., Minneapolis, Minn	Bryant, Illinois	17.53	31.85	44.42	19.91	3.82	11,434 dry
Union Elec. Lt. & Pr. Co., St. Louis, Mo	Southern Illinois	10.0	30.0	42.0	18.0	4.0	11,600 dry
Union Gas & Elec. Co., Cincinnati, Ohio	Island Creek	3.89	36.46	52.25	7.4	3.63	13,150 dry
United Rwy. & Elec. Co., Baltimore, Md	Pool No. 9 (Ash fusion temperature 2160° F.)	2.39	17.88	69.89	9.38	2.00	13,700 dry
Utah Light & Rwy., Salt Lake City, Utah	Bituminous	6.0	....	....	6.0	0.5	12,000 dry
Western Lt. & Pr. Co., Lafayette, Colo	Northern Colo., lignite from Electric Mine, Denver	18.0	34.0	41.0	7.0	0.7	9,600 as fired
Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa	Pittsburgh slack	3.6	32.0	56.0	9.0	1.5	13,750 dry
	M. C. & G., No. 3528	5.52	34.81	57.38	7.81	1.5	13,500 dry
West Penn. Power Co., Connellsville, Pa	P. P. C., No. 1, unw	0.94	32.84	49.96	13.26	1.20	11,748 dry
	P. P. C., No. 2. unw	0.55	32.80	56.55	10.10	0.79	12,713 dry
Wilmington & Phila. Tractoin Co., Wilmington, Del	S. Fork, Pal, regions	3.0	....	....	9–15	....	13,500 dry
							14,000 dry
Winchester Repeating Arms Co., New Haven, Conn	Eastern	2.0	1.90	71.0	8.0	1.5	14,200 dry
Wisconsin & Minnesota Lt. & Pr. Co., La Crosse, Wis	Illinois	3.0	36.0	30.0	15.0	....	10,500 as fired
Wis. Condensed Milk Co., Burlington, Wis	Harrisburgh screenings	7.12	34.55	50.68	7.65	2.23	13,439 dry

TABLE III
WEIGHTS OF VARIOUS COALS

Sample No.	Source of Coal				Size	Weight per Cubic Foot	
	State or Country	County or Province	Place	Mine or name of Coal		Coal as Received	Broken Coal
						Pounds	Pounds
1	Alabama	Bibb	Blocton	Blocton	Domestic	45.5	
2	Alabama	Jefferson	Pratt City and Ensley	T. C. I. group	Run-of-mine	54.0	
6	Arkansas	Franklin	Denning	Denning No. 2	Lump	53.0	
9	Arkansas	Franklin	Denning	Denning No. 2	Run-of-mine	59.0	
10	Australia	New South Wales	Abermain	Abermain	Run-of-mine	49.5	
11	Australia	New South Wales	Cessnock	Abedare	95–5–0 *	43.0	
14	Canada	Vancouver Island, British Columbia	....	New East Wellington	....	50.0	49.5
15	Canada	British Columbia	Michel	Michel	Run-of-mine	55.5	
17	China	North China	Kaiping field	Chao Ko Chwang	....	49.5	
18	China	North China	Kaiping field	Tongshan and Chao Ko Chwang collieries	....	52.5	52.0
24	Colorado	Las Animas	Augilar	Royal	Lump	50.5	
29	Georgia	Walker	Pittsburgh	Durham	60–10–30 *	54.0	
30	Illinois	Williamson	Herrin	Jeffrey	....	49.0	
33	Illinois	Saline	Eldorado	Eldorado	Lump	49.5	
37	Illinois	La Salle	Cedar Point	No. 5	80–15–5 *	46.0	
44	Indiana	Greene	Jasonville	Calora	Lump	44.0	
47	Indiana	Greene	Jasonville	Green Valley	85–10–5 *	48.5	
51	Indiana	Vermilion	Clinton	Jackson Hill No. 5	80–15–5 *	44.0	

53	Iowa	Appanoose	Centerville	Streepy	60–25–15 *	46.5
55	Japan	....	....	Meneji	....	51.5
64	Kansas	Leavenworth	Leavenworth	Leavenworth Nos. 1 and 2	80–15–5 *	50.0
66	Kentucky	Bell	Cary	Cary and Castro	98–2–0 *	54.5
73	Kentucky	Webster	Clay	No. 7	90–5–5 *	46.5
79	New Mexico	McKinley	Gibson	Navajo	80–15–5 *	46.5
80	New Zealand	....	Westport	Millerton	10–20–70 *	53.0
82	Ohio	Athens	Nelsonville	Stalter No. 1	95–5–0 *	49.0
86	Oklahoma	Pittsburgh	Buck and Carbon	....	....	45.5
90	Pennsylvania	....	....	Delaware, Lackawanna & Western anthracite	Egg	56.0
94	Pennsylvania	....	....	ditto	Egg	58.0
112	Pennsylvania	Armstrong	Leechburg	Armstrong	75–20–5 *	50.0
116	Pennsylvania	Cambrai	Twin Rocks	....	5–15–80 *	52.5
124	Pennsylvania	Clarion	Clarion	Cronk No. 5	60–20–20 *	49.5
128	Pennsylvania	Clearfield	Hawk Run	Acme	80–15–5 *	49.5
148	Pennsylvania	Somerset	Somerset	Quemahoning Creek No. 1	20–20–60 *	53.0
152	Tennessee	Anderson	Briceville	Cross Mountain No. 1	80–18–2 *	46.0
161	Utah	Rhea	Hiawatha	Haiwatha	95–0–5 *	44.5
162	Washington	Rhea	Black Diamond	....	(Briquets)	42.0
163	Washington	Kittitas	Roslyn	Nos. 1 and 3	60–30–10 *	53.5
165	West Virginia	McDowell	Davy	Nos. 1–5	94–3–3 *	53.0
166	West Virginia	McDowell	....	Pocahontas 3 and 4 beds	3–5–92 *	57.5
172	West Virginia	....	....	Kanawha region	75–15–10 *	55.5
174	Wyoming	Hot Springs	Gebo	Owl Creek	....	52.5
175	Wyoming	Sheridan	Kooi	Kooi	....	45.5

* Percentages of lump, nut, and slack.

CHAPTER IV

COMBUSTION CHARACTERISTICS OF COAL AND SELECTION OF SUITABLE STOKER EQUIPMENT

The United States produces every variety of coal from anthracite to lignite. These different coals possess widely differing characteristics requiring conditions peculiar to each particular coal for the best combustion results, and to meet these conditions, a great variety of mechanical stokers have been developed. Each stoker has been developed to meet some certain set of conditions and after proving successful, has gradually enlarged its field of application.

In general, it may be said that any stoker will burn practically every coal with some degree of success, but that no stoker is a commercial success with every coal. It is necessary, therefore, to determine for a given coal, those stokers which will burn it successfully and exclude from consideration those not suited. Stokers have proven unsatisfactory in a greater percentage of cases than any other piece of power plant apparatus, and the great majority of these failures were due to improper selection rather than to any inherent weakness of the stoker selected.

It is necessary as a preliminary to the selection of a stoker to divide those available into groups, as given in Chapter 2, and to determine the adaptability of these groups to burning the different grades of coal.

It is also necessary to explain what will be understood hereafter by certain terms which are commonly used in a rather indefinite manner.

Combustion Rates.—Many curves have been plotted showing the relation between fuel bed resistance and combustion rates for the various grades of fuel but it will often be found that the results of an actual test differ greatly from the commonly given values. The reason for this is the varying per-

centage of dust and small particles in the coal as well as the amount of surface moisture present. The amount of dust which any coal contains will depend upon the structure of the coal and the amount of handling it has received. Coal which is very brittle will often be received containing a very large percentage of dust whereas the harder grades will contain a comparatively small percentage of dust. The amount of dust present has a decided bearing on the resistance to the flow of air, and this is one of the principal reasons why the fuel bed resistance in a particular case may differ largely from the average values usually given. A fuel containing 30% of particles which will pass through a one-eighth inch round hole, will offer about 50% greater resistance to the flow of air than a fuel containing no such particles. This condition does not exist after the entire mass of fuel is in active combustion but it does retard ignition and appreciably reduces the capacity that can be secured under a given set of conditions. This excessive fuel bed resistance can be largely overcome by adding sufficient surface moisture to agglomerate the dust. This water should not be added in the stoker hopper but should be mixed with the coal before it is delivered to the coal bunkers. The water then has an opportunity to become evenly distributed through the entire mass and produce the desired result without requiring an excessive amount of moisture.

When the correct amount of moisture has been added and thoroughly mixed with the coal, it should stick together when tightly squeezed in the hand. The addition of moisture makes the fuel bed more porous, not more compact, as is commonly supposed. The rapid evaporation of this moisture when the fuel is introduced into the furnace produces steam which tends to keep the mass broken up and porous. It is for this reason, the wetting of certain coals greatly assists in their combustion. From 5% to 8% surface moisture is usually sufficient and the improved fuel bed conditions which result more than offset the loss produced by the evaporation of this percentage of moisture.

It is unfortunate that the practice of making a screening test and a surface moisture determination is not a part of every boiler test. Such data would assist in explaining a number of apparent discrepancies in the results secured.

Eastern Coals.—The low volatile, low ash, high carbon coals of Pennsylvania, West Virginia, and Virginia, form a well defined class. They contain from 16% to 22% volatile, 68% to 77% fixed carbon, 3% to 10% ash, 2% to 6% moisture, and from 14,200 to 15,000 B.T.U. per lb. dry. The peculiarity of such coal is that when subjected to high temperature, it swells and tends to cake together into a solid mass. For satisfactory combustion it is necessary that the fuel bed be uniform and porous enough to allow the air required for combustion to pass through and it is therefore necessary to agitate this coal, especially during the early stages of combustion, to secure the best results. Fortunately, the fusing temperature of the ash is very high (2500° F. or higher) and the ash content low, so that the necessary agitation does not cause clinker trouble.

Side feed and front feed stokers provide a sufficient agitation to keep the fuel bed broken up in a uniform and porous condition and therefore can burn this coal satisfactorily if the proper adjustments are maintained and the fire not allowed to become too heavy. In the case of a heavy fuel bed, the action of the grates is not sufficient to agitate the mass throughout its full depth, and the surface becomes caked to such an extent that the free passage of air is not possible.

On account of the high percentage of fixed carbon this coal is slow burning and the amount that can be burned with a given draft is less than in the case of other bituminous coals. Natural draft is usually employed with this type of stoker, and with .50″ draft over the fire, which is about as much as is usually available, combustion rates of more than 35 lbs. per sq. ft. of grate surface per hour cannot be secured without excessive loss of combustible to the ash pit. Forced draft can be applied but a heavier fire is then required for best results and if the thickness is greater than about 6″ the grate motion is not sufficient to keep the surface of the fuel bed properly broken up. Sufficient grate surface should therefore be installed to burn the maximum amount of coal required at a rate not greater than 35 lbs., and under these conditions, very satisfactory performances should be secured. There should be no serious clinker trouble and on those stokers equipped with

continuous ash removing mechanism, the cleaning is automatic and continuous.

All stokers of the underfeed type are well adapted for burning Eastern coal. The tendency of the coal to swell accentuates the action of the stoker to produce a fuel bed of unusual thickness (24″ or greater) and the pushing action of the feeding mechanism keeps the fuel bed broken up and porous. The fuel bed is in the proper condition for the employment of high air pressure and combustion rates of 60 lbs. per sq. ft. of grate area can be maintained for long periods of time and about 70 lbs. per sq. ft. for two or three hour peaks. The high fusing temperature of the ash and the low percentage of ash in the coal combine to make the cleaning periods infrequent and of short duration. High boiler ratings can be carried on account of the high combustion rates possible and the high heating value of the coal, and unusually good efficiency of combustion is secured on account of the adaptability of the coal to the fuel bed conditions, secured with this type of stoker.

The fuel bed conditions are ideal for banking and quickly bringing banked boilers into service at high ratings. A properly banked unit can be brought up to 200% rating in four or five minutes, thus providing a degree of flexibility which is highly essential in certain types of central stations. The fuel bed can be comparatively close to the boiler heating surface without producing smoke and a large amount of heat is transmitted from the fuel bed to the boiler by direct radiation.

Traveling grates unless provided with means for agitating the fuel during the early stages of combustion will not give satisfactory results with Eastern coal. The fuel, being carried from front to rear of the furnace without agitation, tends to form a solid mass of coke which seriously interferes with the supply of air through the fuel bed. The air will finally break through in spots and the fuel will burn intensely but unevenly at the rear of the furnace. The result is that large amounts of unburned coke are discharged to the ash pit and the grates are overheated in spots where the air does not break through. Agitating devices have been applied to the traveling grate which break up the mass of coke and produce a fairly uniform and porous fuel bed and satisfactory operation can be secured.

Combustion rates up to 40 lbs. per sq. ft. per hour can be secured with this arrangement, but above this rate, the ash pit loss increases rapidly and burning of the grate surface becomes serious. Further development along this line must depend upon the application of forced draft. This requires a different design, as attempts to apply forced draft to the standard stokers of this type have generally proven unsuccessful.

Experience with traveling grates has demonstrated that while agitation of Eastern coal is desirable it is not absolutely necessary. It is possible by carrying a thin fire and a strong draft, to develop a region of high temperature where the fuel enters the furnace, and consume the volatile without caking the solid particles in the fuel, but the thickness of fuel bed is not sufficient for good operating results. By the application of forced draft, the fuel bed can be increased to the proper thickness and the air supply regulated to secure the desired temperature and combustion at the front of the furnace. Under these conditions satisfactory results are to be expected.

Pittsburgh Coal.—The high volatile coals of Western Pennsylvania, Eastern Ohio, Eastern Kentucky, and parts of West Virginia may be grouped under the heading of Pittsburgh coal. They contain from 30% to 38% volatile, 50% to 60% fixed carbon, 5% to 12% ash, 3% to 10% moisture and from 13,200 to 14,000 B.T.U. per lb. dry. All these coals possess caking qualities to a greater or less degree but not to such an extent as the Eastern coals, although there is no clear line of division between them.

Overfeed stokers burn this coal very satisfactorily if provided with proper draft and setting conditions. The caking tendencies are not sufficient to cause trouble if proper stoker adjustments are maintained and the draft is sufficient for the combustion rates desired. Fuel beds of more than 6″ thick have a tendency to cake and become irregular, resulting in increased ash pit loss and lowered efficiency.

The large amount of heavy hydro carbons make this coal difficult to burn smokelessly and overfeed stokers require furnace designs combining a considerable amount of brick work and a long flame travel. The addition of brick work to a furnace, especially in the form of arches, increases the furnace

temperature, and when this type of stoker is employed for burning Pittsburgh coal at high rates of combustion, clinker formations will become troublesome unless the arrangement of brickwork is carefully considered.

Combustion rates of from 30 to 35 lbs. per sq. ft. of grate surface per hour can be secured for considerable periods of time and peak load combustion rates of from 40 to 42 lbs. can be maintained for two or three hours, with a furnace draft of from 5″ to 6″.

The underfeed type has come into extensive use in all districts where Pittsburgh coal is burned. The feeding action of the stoker is sufficient to keep the fuel bed broken up and in a uniform condition for any thickness of fuel bed which may be carried on this type of stoker. The thick mass of burning fuel provides the necessary condition for the distillation and combustion of the hydro carbons with the consequent elimination of smoke without the use of firebrick arches. While the percentage of ash is higher than in Eastern coal, requiring more frequent dumping of refuse, this feature is satisfactorily taken care of with the designs of underfeed stokers now used and is not considered objectionable in those plants using this type of stoker.

On account of the high volatile content the combustion is not so complete in the fuel bed itself as in the case of Eastern coal and a large combustion space between the fuel bed and the boiler heating surface must be provided varying in size according to the nature of the coal and the combustion rates which are desired.

Combustion rates of from 40 to 45 lbs. per sq. ft. of grate surface per hour can be maintained for long periods of time and from 60 to 65 lbs. per sq. ft. for a peak load of two or three hours.

Chain grate stokers handle most Pittsburgh coal satisfactorily in spite of its slight tendency to cake, although there are some coals in this district having strong caking tendencies for which the chain grate is not suitable. Heavy fuel beds have a tendency to produce uneven fires on account of the slight caking tendency, but if the fuel is fed not more than five or six inches in thickness this tendency is not great and uniform

fires can be maintained over the entire grate surface. On account of the relatively high percentage of fixed carbon it is found desirable to make the stokers ten feet or more in length in order to more completely burn out the carbon in the ash.

In this connection it should be noted that for a given rate of combustion per unit area of grate surface, the length of time that any one particle of fuel is in the furnace is independent of the length of grate surface provided the same fuel bed thickness is maintained. For instance, a stoker 15′ long burning coal at a given rate per sq. ft. must travel 50% faster than a stoker 10′ long burning coal at the same rate per unit area, and in both cases the length of time a particle of fuel is in the furnace will be exactly the same. For operating reasons, however, it is necessary that a grate speed considerably in excess of that actually required for the maximum combustion rate be provided to enable the operator to take care of a sudden demand when fires may be thin or completely burned out at the rear. This maximum speed required for emergency is practically the same for any length of grate and it is apparent that the danger of discharging excessive amounts of combustible to the ash pit will be greater with a short stoker.

Combustion rates of from 30 to 35 lbs. per sq. ft. of grate surface per hour can be maintained for long periods of time, and 40 lbs. or slightly more can be maintained for peak loads of two or three hours. The draft required will be from .5 to .6″ for maximum combustion rates. A combustion rate as high as 50 lbs. can be secured for short intervals by running a thin fire, but it will be done at the expense of a very heavy loss to the ash pit.

Michigan Coal.—Michigan coal contains from 8 to 15% moisture, 30 to 35% volatile, 45 to 50% fixed carbon, 10 to 18% ash and from 12,000 to 12,500 B.T.U. per lb. dry. This coal is very free burning but has a considerable tendency to clinker. The amount available is relatively small and it is used in only a few plants.

Overfeed stokers are used successfully with this coal. The free burning characteristic combined with the tendency to clinker requires that less agitation be given the fuel both for the reason that agitation is not required to keep the fuel bed

porous and uniform and because too much agitation aggravates the tendency to clinker. With proper adjustment, however, stokers of this type do not get into clinker trouble and on those stokers designed for continuous removal of ash, this part of the mechanism will work satisfactorily. Combustion rates of from 30 to 35 lbs. can be maintained for long periods, and combustion rates of 40 lbs. for periods of two or three hours with a furnace draft of .45″ to .5″, but clinker troubles develop at this rate of combustion.

Underfeed stokers will burn this coal at combustion rates of about 40 lbs. per sq. ft. per hour long periods and from 50 to 55 lbs. per sq. ft. for two or three hour periods. The heavy fuel bed provides the necessary condition for the distillation and combustion of the hydro carbons and smokeless combustion is secured without the assistance of firebrick arches. The combustion rate is limited by the rate at which refuse can be disposed of, as this coal will give serious trouble with clinkers if combustion rates in excess of 60 lbs. are maintained for long periods of time.

Chain grate stokers handle this coal at combustion rates of from 30 to 35 lbs. per sq. ft. for long periods and 40 lbs. or slightly more for two or three hour periods with a draft of from .5″ to .6″ in the furnace. The free burning characteristics permit of the desired thickness of fuel bed without any tendency of the fuel to cake. Uniform fires result and with proper provision at the rear of the furnace, ash and clinker are disposed of without the necessity for resorting to manual labor.

Illinois, Indiana and Missouri Coal.—The coals grouped under this heading vary widely in analyses but have similar characteristics so far as their action in a furnace is concerned. These coals contain from 8 to 18% moisture, 38 to 53% fixed carbon, 28 to 36% volatile, 8 to 20% ash, and from 11,000 to 12,500 B.T.U. dry.

There are a few mines in Indiana which produce coal having some caking properties which would not properly come under this heading. Although somewhat higher in ash and lower in heating value than Pittsburgh coal, their action in a

furnace is much more like that of the average Pittsburgh coal than it is of the other coals of Indiana and Southern Illinois.

On account of their free burning nature, they require no agitation to prevent caking and burn best on the overfeed type of stoker with just sufficient grate motion to cause a continuous feed. A greater agitation simply aggravates the tendency to clinker. The coals of this group containing less than 15% ash are handled satisfactorily on the overfeed stoker and without serious clinker troubles at combustion rates up to 30 lbs. per sq. ft. per hour for long periods and from 35 to 40 lbs. for two or three hour periods. For this latter combustion rate a furnace draft of .45 to .5″ is required. Combustion rates up to 45 lbs. can be maintained for short periods but at the expense of greatly increased ash pit loss, the production of objectionable smoke and a considerable amount of hand labor. Those coals having over 15% ash can be burned at slightly lesser combustion rates on account of the ash accumulations. Those stokers designed to continuously remove the ash will do so up to 30 lbs. combustion rate, but at maximum combustion rates, hand cleaning must be resorted to at intervals.

The use of underfeed stokers in plants burning Illinois coal is of recent date although a number of large plants have used this stoker with sufficient success to warrant their installing additional equipment of the same kind. The nature of the fuel bed is such that prompt ignition and smokeless combustion are secured without the assistance of firebrick arches. Combustion rates of from 40 to 45 lbs. per sq. ft. can be maintained for long periods and from 50 to 55 lbs. per sq. ft. for two or three hours. At combustion rates up to 50 lbs. per sq. ft. the removal of clinker is effected without trouble, but when combustion rates exceed 65 lbs., the ability to dispose of the refuse becomes the limiting factor. The use of water boxes along the clinker line to overcome this difficulty has proven satisfactory where combustion rates of over 50 lbs. per sq. ft. are to be carried for long periods of time. The lowest grades of this fuel containing from 15 to 18% moisture and 20% or more of ash ignite very readily without the use of firebrick arches and contrary to the opinions of those who made some

of the first installations a firebrick arch is not required to stimulate ignition.

Chain grate stokers were brought to their present state of development in the districts where these coals are commonly burned. The free burning characteristics make the chain grate suitable and the method of disposing of ash is such that with the proper construction at the rear of the furnace there is no trouble disposing of the refuse. Combustion rates of from 30 to 35 lbs. can be maintained for long periods and from 40 to 45 lbs. for peak loads with a furnace draft of from .5 to .55″.

The tendency to design boilers with a narrow furnace width for a given capacity and the increasing tendency to operate boilers at high ratings is met with this type of stoker by increasing the length of the grate. The long grate surface makes it possible to develop a furnace design comprising a long ignition arch which is necessary for prompt ignition with the higher speed of grate travel made necessary by the long stoker.

Iowa Coal.—The coals from Iowa which are available for use in steam plants are of much lower grade than would be apparent from the analyses usually given. The analyses are usually made on mine samples and will run lower in ash and higher in heating value than the fuels available for steam purposes. This is true to only a small degree with the better grades of coal, in the United States, but Iowa coal occurs in relatively thin veins and a considerable amount of dirt and rock find their way into the screenings which are usually used in steam plants. It is not uncommon to find actual samples which run from 15 to 20% moisture, from 25 to 30% ash and not over 8000 B.T.U. per lb. as fired, and this is about the grade of coal that should be considered in selecting stoker equipment, if coal is to be bought in the open market.

Overfeed stokers handle this coal but at limited combustion rates, the coal being very hard to ignite and requiring long arches for maintaining the high temperatures at the point where the fuel enters the furnace which are necessary for prompt ignition. The arch construction aggravates the tendency of this coal to clinker and considerable trouble from this

source develops at combustion rates of over 20 lbs. per sq. ft. per hour. The draft required is somewhat higher than would be necessary for the better grades of free burning coal because the high ash content and clinkering tendencies produce a fuel bed which offers an unusual amount of resistance to the flow of air, a draft of from .35 to .4″ being required for combustion rates of from 20 to 25 lbs. Combustion rates in excess of 25 lbs. can only be secured at the expense of an excessive amount of hand labor and a large loss of fuel to the ash pit.

The presence of a large amount of readily fusible ash adds to the difficulty of burning this fuel without an excessive ash pit loss. If small particles of clinker which apparently contain no combustible be broken open, it will be found that the ash has fused over a particle of partially burned coal cutting off the air supply and preventing the final combustion of such fuel. This condition is aggravated by agitating the fuel bed and best results can be secured when this agitation is kept at a minimum.

Underfeed stokers of the self-cleaning type have recently been applied in a number of plants burning Iowa coal. Ignition is maintained without the assistance of firebrick arches and the nature of the fuel bed is such that arch constructions are not necessary for smokeless combustion. The high ash content and tendency to clinker necessitate frequent cleaning of the fires and at high rates of combustion, considerable manual labor is involved unless the furnaces are provided with water boxes or some other arrangement for preventing the formation of clinker on the furnace walls. The presence of a large amount of ash does not seriously affect the ability to burn the fuel and the limitations as to combustion rates are determined by the ability to dispose of the refuse deposited on the dump plates. Combustion rates of from 35 to 40 lbs. per sq. ft. can be maintained for long periods and about 45 to 47 lbs. per sq. ft. can be burned for periods of two or three hours. The use of water boxes or some other device for preventing the adhesion of clinker to the brickwork should be installed if combustion rates of over 50 lbs. per sq. ft. are desired.

Chain grate stokers with arch construction of special design give good service on this grade of coal. The chief problem

is one of continuous ignition but furnace designs obtaining this result have been developed. There is a tendency even after the coal has been ignited on the surface for that part lying directly on the grate surface to ignite very slowly if at all, and improper furnace design results in some of this coal passing to the ash pit almost entirely unburned. Continuous ignition and the combustion of the greater part of the fixed carbon can be maintained at combustion rates up to 30 lbs. per sq. ft. with a draft of from .35 to .4″ in the furnace. Combustion rates in excess of 30 lbs. should not be depended on for long periods of time because it is difficult to maintain ignition and to burn out the fixed carbon at higher rates. The arch construction necessary for continuous ignition has a tendency to produce clinker but the action of the grate is such that this is continuously discharged to the ash pit and will not cause trouble in the furnace if the walls are kept clear of clinker and the fuel is not permitted to pile up at the bridgewall.

The forced blast traveling grate presents attractive possibilities of utilizing low grade Iowa coals. Ignition is easily secured because the air supply can be regulated to maintain the desired combustion rate and temperature at the front of the furnace even during periods of light load. A substantially constant condition can be maintained in the ignition zone for all ratings and the length of fire and combustion rate on the remainder of the grate surface, regulated to suit the load requirements.

In some localities washed Iowa coal is available which is of much better quality than that mentioned above and compares quite favorably with the high ash coals of Northern Illinois although it should not be considered in the same class as the Southern Illinois fuels. It is especially important that Iowa coal should be of suitable size as a large percentage of coarse coal retards ignition by admitting too much cold air at the front of the furnace. Screenings which have passed through a 1¼ to 1½″ screen are of suitable size but larger particles if present in large quantities will seriously effect the operation.

East Kentucky, Tennessee and Alabama Coal.—The coals from this district contain from 30 to 37% volatile, from 50 to 60% carbon, from 5 to 15% ash, and from 13,000 to 13,500 B.T.U. per lb. dry. These are thoroughly high grade and as a class are practically free burning although the coal from some localities in this district has a considerable tendency to cake. The high volatile content requires that stokers be set with liberal combustion chambers for smokeless operation.

Overfeed stokers both of the front feed and side feed types, provide sufficient agitation to keep the fuel bed in a uniform and porous condition and handle all coals in this district satisfactorily. Combustion rates of from 30 to 35 lbs. can be maintained for long periods and for peak loads, 40 lbs., may be burned for short intervals, with a draft of from .5 to .6″ in the furnace. The low ash coals of this district do not produce an ash layer of sufficient thickness to protect the grates and unless the stokers are properly handled, considerable burning of the grate surface will result. In general however, it may be said that an installation of overfeed stokers will be very satisfactory if surrounded with the proper conditions.

Underfeed stokers are handling this coal successfully. Firebrick arches are not required and the feeding action prevents caking of those coals which have a tendency to do so. Combustion rates of from 45 to 50 lbs. per sq. ft. for long periods and from 55 to 60 lbs. for peak loads can be maintained.

The thick fuel bed provides a means for burning the volatile and this combustion is to a large extent, completed in the fuel bed itself. Liberal combustion chambers are desirable, however, for smokless operation and best efficiency at high combustion rates. The low ash content and the comparatively high fusing temperature of the ash make it possible to operate at high ratings without clinker trouble.

Chain grate stokers handle some coals from this district satisfactorily but are not considered suitable for others. The absence of agitation allows the caking of those coals which have a tendency do so with the result that fuel beds become irregular, allowing excess air to enter through the rear of the grate and the discharge of an undue amount of coke to the ash pit. Those coals having very low ash content do not

sufficiently protect the grate surface in the rear of the furnace and maintenance will be above the normal amount for this type of stoker unless a cooling effect is secured by permitting the entrance of a considerable excess of air in the rear portion of the grate surface. The remaining fuels can be handled successfully at combustion rates of from 30 to 35 lbs. per sq. ft. for long periods and about 40 lbs. for peak loads with a draft of from .5 to .6″ in the furnace.

Those chain grates equipped with mechanism for agitating the fuel bed during the early stages of combustion can burn the caking coals of this district at about the same rate as given above for the standard type of chain grate.

Texas, Oklahoma and Arkansas Coal.—There are three distinct coals available in this district. First, semi-anthracite containing from 10 to 16% volatile, 1 to 2% moisture, 77% fixed carbon and 8 to 18% ash. Second, bituminous coal having from 30 to 35% volatile, 30 to 40% fixed carbon, and 10 to 20% ash, although these coals as actually delivered to the plant may contain as high as 30% ash.

Third, lignite containing from 20 to 35% moisture, 30 to 40% volatile, fixed carbon 30 to 35%, and ash 10 to 15%.

On account of the wide variations in fuels from adjacent localities, it is advisable to secure actual analyses of coal as delivered rather than to depend upon average analyses. The methods of mining and preparation will control the ash content and may have an important bearing on the manner in which these fuels will burn. There are cases where mine samples may show from 15 to 18% ash but where fuels available for steam purposes will run as high as 35 to 40% ash. It is apparent that apparatus designed to burn the former might be entirely unsuited to the fuel as actually delivered.

The semi-anthracite coal being comparatively low in volatile and high in ash is extremely difficult to ignite. Overfeed stokers require special arch constructions to maintain ignition, the high fixed carbon content results in a hot fire after ignition has been thoroughly established and the large amount of brickwork necessary for ignition tends to increase furnace temperatures to such an extent that clinker troubles result from the fusing of the ash. Combustion rates up to 25 lbs. can be

maintained with .4″ furnace draft but this combustion rate cannot be exceeded without considerable clinker trouble and manual labor.

Underfeed stokers ignite this fuel without the assistance of firebrick arches and can maintain combustion rates of 38 to 40 lbs. per sq. ft. This can be increased to 50 lbs. per sq. ft. for peak loads but at high combustion rates the clinker trouble becomes objectionable.

This coal being of a free burning nature can be handled satisfactorily on chain grate stokers with special arch construction suitable for maintaining continuous ignition. Combustion rates up to 30 lbs. per sq. ft. can be maintained for long periods with a furnace draft of about .4″ but attempts at high combustion rates usually result in delayed ignition. The low grade Texas lignite is not used to a large extent for steam purposes and the adaptability of the different types of stoker to this coal can only be fully determined by further experiments. The principal difficulty encountered is that of thoroughly driving off the moisture and burning the fuel in the same furnace. Satisfactory results could unquestionably be secured by a pre-drying process independent of the fuel burning furnace but the expense of this construction added to the cost of the standard stoker equipment is not justified under present conditions. Whether a pre-drying process or a special furnace and stoker construction would be preferable can only be determined by careful experiments which will only be carried out when the fuel is more attractive from a standpoint of comparative cost. With the present development of the art it seems that the forced draft traveling grate offers the best solution of this problem. The indications are that if this fuel were crushed so that no particles would pass over a 1″ screen, that it could be successfully handled on the forced draft traveling grate.

The bituminous coals of Texas are not important from a commercial standpoint because they cover an area which is located a considerable distance from any large fuel burning localities. The coal as delivered for steam purposes often contain 30%, or more of ash, is difficult to ignite and clinkers very badly. It has been successfully handled only on chain

grate stokers built in length greater than ordinarily used and with special arch construction. This coal is free-burning, has no tendency to cake but will clinker with the slightest agitation, forming a sticky mass when hot and a hard brittle clinker when cold. Combustion rates of 25 lbs. per sq. ft. can be maintained but at higher rates there is danger of delayed ignition or the piling up of the fuel at the rear of the furnace which will immediately produce objectionable clinkers.

Colorado Coals.—Colorado produces a greater variety of coals than can be found in any other similar area in the United States. In the Northwestern part of the state, a fair grade of anthracite is to be had. In the district north of Denver there are large deposits of lignite of considerable commercial value also lignite deposits in the vicinity of Colorado Springs. The Western part of the state produces a high volatile free burning coal similar to the best grades of Southern Illinois while in the southern part of the state a high volatile caking coal similar in many respects to the high volatile coking coals of West Virginia is found.

Colorado Anthracite.—This coal is of small importance because it is located at a considerable distance from any large fuel burning districts and is not used to any great extent for steam purposes. It can be burned in the same manner as the anthracite coals of Eastern Pennsylvania which will be referred to later.

Lignite.—Colorado lignite is of greater importance commercially than any other lignite deposit in the United States. Being located in the vicinity of Denver there is a market for large quantities for steam purposes. It is of much better quality than the Texas lignite and contains from 15 to 25% moisture, 8 to 15% ash, 30 to 35% volatile, and from 10,000 to 12,000 B.T.U. dry.

Overfeed stokers ignite this coal satisfactorily when provided with suitable arch constructions and give satisfactory results at combustion rates of from 20 to 25 lbs. per sq. ft. At higher combustion rates ignition becomes uncertain and clinker troubles develop.

This fuel is very light after thoroughly dried and high furnace draft cannot be employed with the fuel bed of the

thickness which can be carried on this type of stoker. There is also considerable difficulty experienced due to avalanching and it requires careful and skillful attention to secure and maintain good fuel bed conditions.

Underfeed stokers ignite this coal continuously and the heavy bed at the point of fuel introduction provides the necessary conditions for the complete driving off of the moisture before the fuel enters the active combustion zone. When thoroughly dried this fuel can be burned very rapidly and while it has a tendency to clinker, the clinker formation is not sufficiently serious to prevent the satisfactory operation and cleaning of the furnace.

A firebrick arch is not required for the purpose of ignition under ordinary conditions although it would prove desirable in case it was desired to maintain high combustion rates for several hours at a time. For ordinary peak load service, it is found that this lignite gives practically the same results so far as the ability to meet sudden demands is concerned as the better grades of bituminous coal. There is at all times a large quantity of fuel in the furnace that has been thoroughly dried out and ignited and in this condition it makes a fuel bed which responds readily to an increase in air supply and makes it comparatively easy to meet a sudden demand for steam. Combustion rates of from 30 to 40 lbs. per sq. ft. can be maintained for long periods and from 50 to 55 lbs. for short peaks.

Due to the lightness of this fuel the high air velocities through the upper part of the fuel bed carry considerable quantities of fine particles up into the combustion chamber which are deposited at the rear of the furnace. This condition produces a tendency for the fuel bed to drift and become heavy over the dump grates. In order to overcome this difficulty, it is desirable to make changes from the standard method of introducing the air so that the air supply to the rear sections can be controlled independent of the air supply to the front sections. This tends to reduce the tendency to drift and at the same time, makes it possible to burn out completely such fuel as does lodge over the rear sections.

Chain grate stokers are used successfully on the various

grades of Colorado lignite the only requirement so far as the fuel is concerned being that it must not be too coarse. If a considerable percentage will pass over a 1½″ screen, it is too coarse for best results and should be reduced to finer size. Suitable furnace designs have been developed to burn this coal at combustion rates up to 45 lbs. per sq. ft. per hour and this combustion rate can be increased with special designs. Surface ignition occurs promptly and the drying process which must precede ignition goes on rapidly enough to permit ignition to the full depth in a travel of two or three feet.

While lignite has a very large percentage of volatile based on dry fuel there is little or no trouble securing smokeless operation for the reason that the furnace constructions required for satisfactory ignition provide the necessary conditions for smokeless combustion.

Colorado Bituminous.—The high volatile bituminous coals both caking and noncaking, burn satisfactorily on overfeed stokers. The action of the grate surface is sufficient to keep the fuel bed in a uniform and porous condition without agitating the fuel a sufficient amount to produce clinkers. Those stokers provided with continuous cleaning mechanism will remove ash continuously except under most severe conditions of overloading when it may be necessary to supplement the action of the cleaning mechanism by a certain amount of hand labor. Combustion rates up to 30 lbs. per sq. ft. can be maintained for long periods, and from 35 to 40 lbs. for short intervals, with a draft in the furnace of from .5 to .55″.

Underfeed stokers will burn all grades of Colorado bituminous fuels. Firebrick arches are not required to maintain ignition but on account of the very high volatile content of many of these fuels a large combustion chamber is desirable for best results. The feeding action of the stoker is sufficient to break up the fuel bed in case there is a tendency to cake and on account of the relatively low sulphur content, clinker troubles do not occur under proper conditions of operation. Combustion rates of from 40 to 50 lbs. per sq. ft. can be maintained for long periods, and from 55 to 65 lbs. per sq. ft. for peak loads.

Chain grate stokers handle most of these coals satisfactorily

although there are a few which have sufficient caking tendencies to make the chain grate undesirable. The high volatile content makes this coal very easy to ignite and the arch construction is therefore determined more from the standpoint of securing smokeless operation than for providing suitable ignition. Those fuels which are free burning will produce even and uniform fires and good operating results can be secured. Combustion rates of from 35 to 40 lbs. per sq. ft. can be maintained for long periods and 45 lbs. or slightly more for short periods, with a furnace draft of from .5 to .6".

Washington and Oregon Coal.—The coal deposits of Washington cover large areas and contain an immense amount of fairly high grade fuel. They have not been highly developed, however, largely on account of the large quantity of fuel oil available at low prices. The rapidly changing conditions of the oil market, however, will result in a large increase in the demand for fuel in those districts which can be supplied from Washington fields. In analysis and characteristics, this coal is quite similar to Illinois fuels and can be burned with practically the same stoking equipment and with the same general results.

Wyoming Coal.—There are a number of deposits of coal in Wyoming but on account of their distance from large fuel burning localities their development has not been rapid. They compare in analysis and characteristics with the free burning middle Western coals, and can be burned on the same stokers with practically the same results.

Dakota Lignite.—There are large deposits of lignite in Dakota of commercial value being only of slightly lower quality than those of Colorado. Until recently, they had received but little attention but present developments in the fuel situation have resulted in greatly increased importance of these fuels. Until recently Minnesota and the Dakotas have been burning Pittsburgh and West Virginia coals. These coals have been able to reach this district because they furnish a suitable return cargo for the ore boats from the Lake Superior Iron district. Transportation conditions have become less favorable, however, and Illinois coal has been finding a ready market in this district. It is necessary to provide for the

winter's supply during the summer and fall to insure against the delays in transportation and the Illinois coal is not entirely suitable for storage on account of the tendency to spontaneous ignition.

The Dakota lignites are not a great distance from the Dakota and Minnesota markets and if they can be satisfactorily burned will offer a solution of the fuel problem in this district. While few plants are burning this fuel regularly, considerable experimental work has been done. Special hand fired furnaces have been developed which are suitable for small boilers and suitable furnaces have been devised for burning this coal on stokers.

If the lignite is crushed to small size it can be burned on chain grate stokers having special arch constructions and the results secured give promise of commercial success. The most satisfactory results have been secured from underfeed stokers equipped with a short firebrick arch over the front of the furnace to increase the furnace temperatures at this point and increase the rate at which the fuel may be fired and completely ignited. Combustion rates of from 30 to 40 lbs. per sq. ft. can be maintained continuously and from 55 to 60 lbs. for peak loads.

Further developments in the application of stokers to the burning of this fuel will probably be along the line of the forced draft traveling grate.

The principal difficulty is that of rapid drying and ignition of the fuel entering the furnace. If a high furnace draft is employed, special provision must be made to prevent air leakage around the front of the furnace because this leakage seriously retards ignition. The forced draft traveling grate can be operated with atmospheric pressure over the fire thus eliminating this air leakage and providing better furnace conditions for prompt ignition. The positive control of air to different portions of the fuel bed also assist in securing the conditions necessary for the successful burning of such fuel.

Anthracite Culm.—Large quantities of anthracite culm are available in the districts adjoining the anthracite fields. This culm has for years been burned with a fair degree of success on specially constructed hand fired grates equipped with force

draft but the successful application of stokers is of more recent date.

Underfeed stokers have been used successfully especially when the culm is mixed with a certain percentage of bituminous coal. Both the capacity and the efficiency which can be secured, decrease with the increase in percentage of culm in the mixture, and at average prices for the two fuels the cost of generating steam will decrease slightly by the use of culm until the mixture contains from 40 to 50% culm. Increasing the percentage of culm above this point so effects both capacity and efficiency that the cost of steam is increased. For the suitable burning of such fuels the mixture must be very thorough. It is difficult with the coal handling equipment usually installed to get a suitable mixture and even then there is a tendency for the two fuels to separate in the coal bunkers. In order to make this method of burning anthracite successful, a specially designed coal handling apparatus is required which will insure a uniform mixture entering the furnace. The cost of this arrangement and the added difficulties in burning mixed fuels makes the whole scheme of rather doubtful commercial value.

Overfeed stokers have been used in a number of cases on straight anthracite but not with complete success. This coal is very fluid and has a decided tendency to avalanche on inclined types of stokers. It also clinkers badly when agitated and the maintenance of a uniform fuel bed is rendered quite difficult, both on account of clinker formations and the tendency to avalanche. Combustion rates of 20 lbs. or slightly more can be secured with a furnace draft of from .4 to .5″ and better results can be secured by the application of forced draft. The ignition is more prompt and the combustion rates can be slightly increased.

The forced draft traveling grate has been most successful in handling this fuel. On account of its very small size, specially designed grate surfaces having small air spaces are required to prevent the sifting of fuel through the grates. Stokers of this type are made in lengths of from 12 to 17 ft. and are divided into compartments for the control of the air pressure to different sections of the fuel bed. By the use of

special arch constructions, prompt ignition is secured which can be maintained at combustion rates up to 50 lbs. per sq. ft. Combustion rates up to 40 lbs. can be secured for long periods of time and since the air supply is under control, uniform fuel beds can be maintained. On account of the lengths in which this type of stoker can be built, a large ratio of grate surface to heating surface is secured and high overload capacities can be developed.

Coke Breeze.—On account of the brittle nature of coke, large quantities of fine particles are broken off in handling both at the coke ovens and at the furnaces where the coke is burned. At such places large piles of coke breeze are nearly always in evidence and if no space is available for piling up this material it is often hauled away to a convenient place and dumped.

Many attempts have been made to burn this breeze which contains from 10,500 to 11,500 B.T.U. per lb. but on account of its low volatile and high ash contents it is difficult to ignite and produces large amounts of clinker. Being very fine, it offers considerable resistance to the flow of air and requires forced draft for its combustion. Hand fired grates equipped with forced draft have been used to a certain extent but the fact that it has been quite common practice at some plants to buy coal for their boiler plants and throw away the coke breeze would indicate the results have not been satisfactory. The principal difficulty has been the rapid clinkering of the fuel bed and the large amount of manual labor required to keep the fires in such condition that reasonable combustion rates could be maintained.

In a few cases overfeed stokers have been used by screening the coke breeze and using the larger particles. The ignition is slow and rather uncertain and clinker formations are very objectionable. The amount of labor involved is high and the rating which can be secured are not high enough to warrant the installation of a sufficient number of boilers to carry the load in this manner.

Underfeed stokers will ignite the coke breeze without the assistance of firebrick arches and it can be burned more satisfactorily than on the overfeed type. Clinker formations are

serious, however, and not only limit the fuel burning capacity but involve a great amount of hand labor. Coke breeze is very abrasive and the forcing of this material through the throats and retorts of this type of stoker results in very high maintenance.

Traveling grates of special design handle this fuel much more successfully than it can be handled in any other manner. On account of the large percentage of very fine particles the air space must be very finely divided to prevent sifting and on account of the dense fuel bed, forced draft must be employed to supply the necessary air for combustion. The low percentage of volatile makes this fuel difficult to ignite but arch constructions have been developed which do this satisfactorily. Since there is no relative movement between the fuel and the fuel supporting surface, the abrasion is eliminated and there is no agitation of the fuel during combustion to aggravate clinker formations. The quality of the coke breeze will vary both on account of the quality of coal from which the coke is made and on account of the amount of dirt gathered up with the coke breeze. The ash content in some cases runs from 20 to 25% but this fuel can be burned satisfactorily at combustion rates of from 25 to 40 lbs. per sq. ft. The application of this stoker has made it possible in a number of plants to discontinue the use of coal entirely and at the same time to save the expense of disposing of the coke breeze to a suitable dump.

Bone Coal.—In coal mining operations, it is necessary to remove a certain amount of material containing a large percentage of coal but not of marketable grade. A certain amount of this bone can be disposed of underground but the balance must be hoisted to the surface and carried to a suitable dump. In some localities the bone will have as high as from 11,000 to 11,500 B.T.U. per lb. and from 20 to 25% ash. In other localities, the ash content will run as high as 35% and the B.T.U. from three to nine thousand. Millions of tons of this material as piled up around the mines and until recently, no attempt has been made to utilize it as a fuel.

The forced blast traveling grate will burn this coal satisfactorily and thereby save not only the marketable fuel being burned at many such plants but also solve the problem of disposing of this material.

CHAPTER V

DRAFT

It has already been pointed out that the majority of stoker troubles have been due to faulty application rather than to defects in the stokers themselves. Faulty application, in turn, often resolves itself into a question of draft and this one factor is responsible for more of the troubles encountered with mechanical stokers than all other factors combined. On the other hand, if the draft conditions are good, many other factors which would cause serious trouble in connection with unfavorable draft conditions can be successfully handled and the engineer who makes sure that a proposed installation will have ample draft has every prospect of making a successful installation in spite of some mistakes which may be made.

The increasing tendency to operate boilers at high overloads has introduced another important factor into the draft problem. The high ratings often require special arrangements of boiler baffles introducing an element of uncertainty as to the draft losses at high ratings and unless ample provisions for draft is made, contemplated ratings cannot be developed.

Draft, as the term is commonly used, refers to the difference in pressure between the point where the draft reading is taken and the atmosphere. For instance, if there is said to be a draft of one inch of water at a given point, the pressure at that point differs from the surrounding atmospheric pressure by the amount necessary to support a vertical column of water one inch high. The draft may represent a pressure either above or below that of the surrounding atmosphere but as the term is commonly used by engineers draft represents a certain pressure below atmospheric pressure or in other words, there is a suction at the point indicated. In case the pressure is greater than that of the atmosphere, its is usually termed "pressure"

or "plenum." In the case of a forced draft installation, where the air is supplied to the under side of the grates at more than atmospheric pressure, the amount which this exceeds the pressure of the atmosphere is expressed as "pressure" in inches of water, and the pressure of the gases passing through the boiler will be at less than atmospheric pressure, the amount being expressed as "draft" in inches of water. Since this is the common usage, the term "pressure" will hereafter be used to indicate pressures above that of the surrounding atmosphere and "draft" to indicate pressures below that of the atmosphere.

In practice, draft is produced in three ways—first, "natural draft" which depends upon the difference in weight of a vertical column of hot gases in a chimney and that of a corresponding height of the surrounding air; second, "induced draft," which is commonly produced by means of a fan taking the gases to be handled from a suitable flue at less than atmospheric pressure and discharging them against atmospheric pressure; third, "forced draft," where a fan or blower takes air at atmospheric pressure and discharges it to a duct or wind box at a pressure above that of the atmosphere. In practice, either natural draft or induced draft may be used singly but when forced draft is employed, either natural or induced draft is required to remove the products of combustion from the furnace.

Natural draft.—Since gases expand as the temperature is increased, provided the pressure is maintained substantially constant, the weight per unit of volume will decrease. In the case of a vertical flue or chimney containing hot gases, the weight of these gases will be less than that of an equal column of cold air and the pressure at the bottom of the stack will therefore be less than the atmospheric pressure at the same elevation. There would, therefore, be a tendency for the cold air to flow to the inside of the chimney provided a suitable opening were provided at or near its base. If some means be provided for heating the air as it enters the base of the chimney, a draft at this point will be maintained which will cause a continual flow.

In most draft calculations it is assumed that the chimney

gases have the same density as air at the same temperature and pressure. A column of air one foot square and one hundred feet high will weigh 7.78 lbs. at a temperature of 50° F. while a column of the same dimensions but having a temperature of 500° F. would weigh only 4.13 lbs., a difference of 3.65 lbs. A chimney 100′ high and containing gases at 500° F. with the outside air at 50° F. would therefore exert at its base a pressure of 3.65 lbs. per sq. ft. or .02535 lb. per sq. inch, less than atmospheric pressure.

One cubic inch of water weighs .0361 pound and the height of water column to balance the chimney effect will be $\frac{.02535}{.0361} = .70''$. In other words, the chimney will produce .70″ draft under the above conditions.

When a supply of heated air or gas is delivered to the bottom of the chimney, a flow will be maintained according to the familiar formula for falling bodies:

$$V^2 = 2\,gh,$$

where V = velocity in feet per second;
G = acceleration due to gravity;
H = head or "draft."

If the gases passed up the chimney without friction, the velocity would be proportional to the square root of the draft, but on account of friction against the inside surface of the chimney, the flow is somewhat retarded. The actual draft at the base of a chimney is, therefore, dependent upon the gas velocity and the character of the inside surfaces as well as upon the height and the temperature difference between outside air and chimney gases. The difference in weight and the actual draft available in an operating chimney represents the chimney friction and the increases with the velocity. When a chimney is overloaded, the available draft drops rapidly due to excessive friction as may be seen from the curves of chimney capacity (Fig. *56*).

The capacity of a chimney is determined by the weight of gas it will handle in a given time and it therefore follows that the density must be considered as well as the velocity. An increase in gas temperature will increase the velocity but there

is also an increase in friction and a decrease in density. Where the gas temperature is about 625° F. the capacity of a chimney has reached the maximum, and a further increase in temperature will increase the draft intensity but the weight of gas handled will decrease because the density will decrease more rapidly than the velocity will increase.

The following formula can be used for determining the friction loss in chimneys:

Formula A. $$\Delta D = \frac{fW^2CH}{A^3},$$

in which D = draft loss in inches of water;
W = weight of gas in pounds per second;
C = perimeter of chimney in feet;
H = height of chimney in feet;
f = a constant with the following values at sea level:

.0015 for steel chimneys,	temperature of gases 600° F.
.0011 for steel chimneys,	temperature of gases 350° F
.0020 for brick lined chimneys,	temperature of gases 600° F.
.0015 for brick-lined chimneys,	temperature of gases 350° F.

The static draft will be KH in which K is a constant, having the following values based on 60° F. outside air and 14.7 lbs. per sq. in. atmospheric pressure.

Temperature Chimney Gases	Constant K
750	.0084
700	.0081
650	.0078
600	.0075
550	.0071
500	.0067
450	.0063
450	.0058
350	.0053

The available draft will be

$$KH - \left(\frac{fW^2CH}{A^3}\right).$$

The curves (Figs. *55* and *56*) have been plotted from results calculated by this method and will be found sufficiently accurate for all practical purposes. It should be noted

that the formula for chimney performance are based on carrying capacity in terms of weight and in determining the corresponding horse power, a value must be established for the weight of gas handled per horse power. Sixty pounds of gas per horse power is an average value for good operation and where there is not a large amount of leakage through boilers not in service. Where a number of boilers, some of which are idle, are served by one chimney, this leakage will be large and it should be taken into account in determining the weight of gas handled per horse power developed.

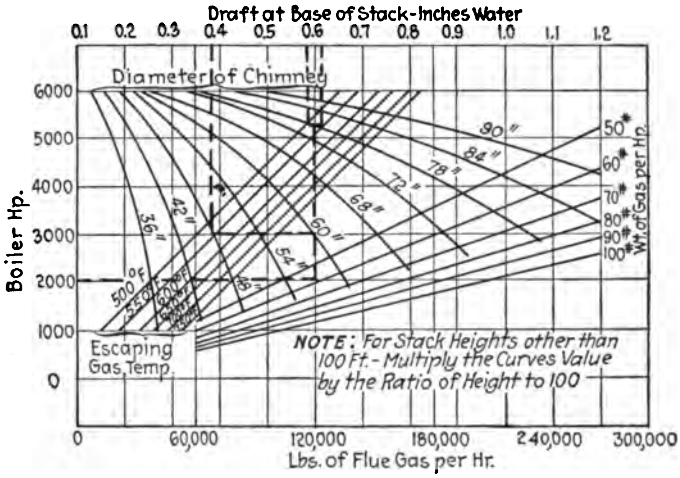


FIG. 55.—Performance of 100′ Stacks from 36″ to 90″ Diameter.

As an illustration of the use of these curves, assume that it is desired to determine the correct chimney size for 2,000 boiler H.P. output. It is first necessary to establish values for weight of gas per H.P. and exit temperature. Sixty lbs. of gas per H.P. represents good operation and from seventy to seventy-five lbs. if fair. First, locate the intersection of the horizontal line for 2,000 H.P. with the diagonal line representing weight of gas per H.P., then project vertically to the curved lines of chimney diameter. A horizontal line through this intersection will in turn intersect the diagonal lines representing escaping gas temperature. A vertical line is then drawn through this latter intersection to the scale of chimney

draft at the top of the diagram and the draft that would be produced by a chimney of the given diameter and 100 ft. high is read from this scale. For example, a 60″ chimney 100″ high would produce a draft of only .39″ with a load of 2,000 H.P. In general it may be said that a chimney that will not produce at least .55″ draft with gases at 500° F., for each 100 ft., in height, is overloaded and the frictional resistance is too great due to excessive velocities. The 60″ chimney would therefore be too small. The selection would lie between the

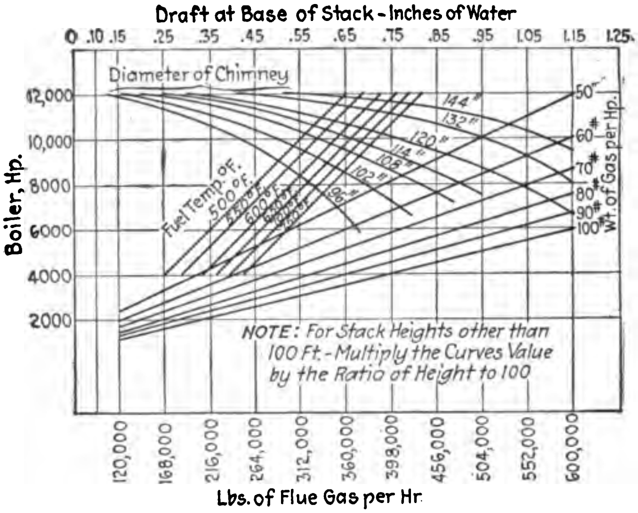


FIG. 56.—Performance of 100′ Stacks from 96″ to 144″ Diameter.

72″ size which will produce .59″ draft per 100 ft. and the 78″ which will produce .62″ per 100 ft. It is apparent that for a given draft at the base of the stack, a lesser height will be required with the greater diameter.

Assume that 1.10″ must be available at the base of the stack, the 72″ size must be $\frac{110}{59}\times 100=187$ ft. high, while the 78″ size must be $\frac{110}{62}\times 100=177$ ft. high.

The choice between these two sizes will depend upon first cost and such local conditions as may effect the selection.

In the case of natural draft, the static draft must overcome all resistances to flow which are as follows:

1. Loss through fuel bed and grate
2. Loss through boiler
3. Pressure required to create velocity of gases leaving the boiler
4. Damper loss
5. Breeching loss
6. Friction loss in chimney

A number of formulae have been developed for determining certain of these amounts but they depend to such an extent upon the values selected for certain constants that their application is of doubtful value. It is known that the temperature of gases in a chimney is less near the top than at the point where the gases enter, due to radiation and to leakage of cold air into the chimney, but no data are available from which the amount of this difference can be determined accurately. The relation between static draft and that available for any given operating condition will depend upon a number of variables, the principal ones being the diameter of the chimney, the nature of its surface, and the velocity of the gases.

Of the above losses, the first and second are most important and of greatest amount. The method of analyzing these losses can best be explained by reference to Fig. 57, which shows a cross section through boiler and stoker. Provision should be made to take draft readings at the points indicated and connections to the draft gauges should be carefully made to insure an absence of leaks which affect the accuracy of the readings. If these readings are to be of any value, they must be taken under operating conditions, with a good fire on the grates and gas analyses should be made to determine the combustion conditions. Notes should be made recording the fuel bed conditions, gas analyses and ratings developed. These data are necessary as they affect the draft losses and no conclusions can be drawn from draft readings unless accompanied by such information. In case an unusual loss is encountered between any two points, such as B and C, the draft gauge can be corrected as shown to read this loss directly and the effect of

any change in conditions will be detected immediately. The values given represent actual results of an investigation but are used merely for purposes of illustration and not to establish standard values for the type of boiler shown.

The performance of a chimney was first presented in convenient form by William Kent in 1884 and the table of chimney sizes calculated from the formula given has been almost universally used by engineers since that time. This table is based

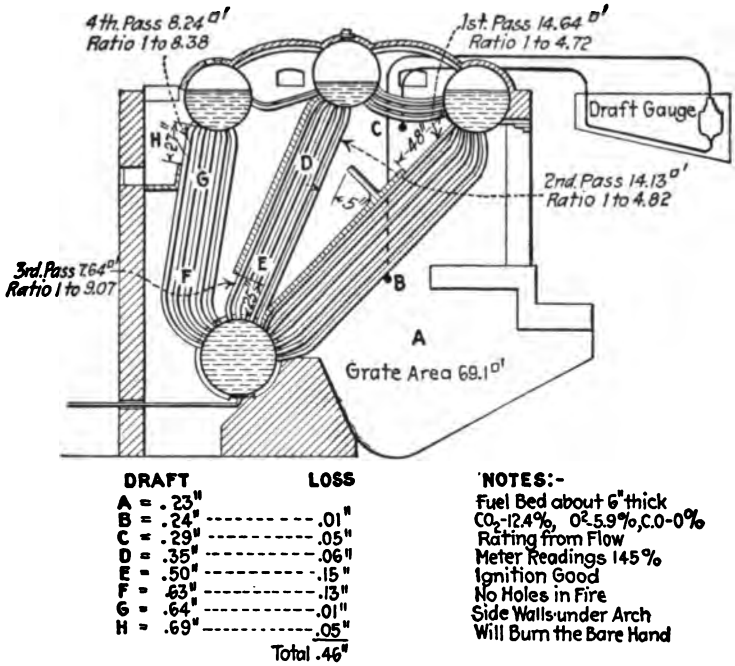


FIG. 57.—Analyzing Draft Losses through Boilers.

on the use of five pounds of coal per boiler H.P., and twenty pounds of air per pound of coal. The height of the chimney must be determined independently of this table by the draft which must be available at the base of the chimney to overcome the various losses of fuel bed, boiler, damper and breeching at the ratings for which the installation is designed and many mistakes have been made by engineers due to their failure to make proper allowance for these losses.

A chimney which would be of the proper size to produce draft for two five hundred horsepower boilers operating at rating, would be entirely unsuitable for one of these boilers operating at 200% rating for the reason that the draft loss through the fuel bed and the boiler is very much greater at 200% rating than at rating and the chimney which was right for two 500 H.P. boilers at rating would not produce the draft intensity required to overcome these losses.

In the ordinary chimney calculations, sea level conditions of atmosphere are assumed. The error due to this assumption is slight for elevations up to 1,000′ and it is not customary to make corrections but when plants are located at greater altitudes, it is necessary to make allowance for the existing atmospheric conditions. Owing to the lower atmospheric pressure at high altitudes, the draft intensity produced by a chimney under a given set of conditions is less than at sea level and an increase in height is necessary. The density of the air and flue gases being less at the higher altitudes, an increase in cross sectional area is necessary to handle the same weight of gas at a given velocity. Due to the lower density, there is slightly less friction for a given velocity but this is so small that it can be disregarded.

In proportioning a chimney for high altitudes, one is first selected which would be used under sea level conditions and the height and diameter are then increased by the amount required to correct for the given altitude as shown in Fig. *58*.

Since the height of the chimney depends upon the draft which will be required at its base, it is obviously very important that the various losses which must be overcome be carefully considered and accurately estimated. Failure to do this, may result in a serious mistake and one which is very difficult to correct.

The various losses outlined above will be considered separately.

First, "**Loss through fuel bed and grate.**" In the design of a stoker installation, one of the first things which must be determined is the combustion rate as outlined in Chapter VIII. This combustion rate being known, the fuel bed resistance can be approximately determined for natural

draft stokers from Fig. *59* and for forced draft underfeed stokers from Fig. *60*.

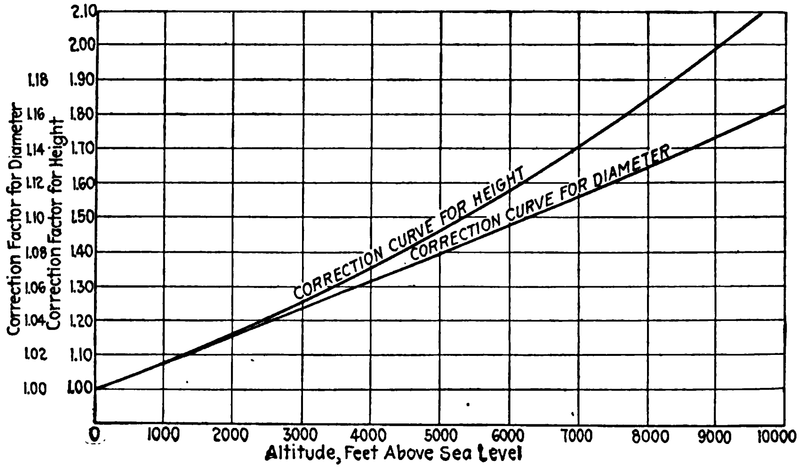


Fig. 58.—Altitude Corrections for Chimney Dimensions.

It should be understood that these curves are only approximate and that actual performances may differ consider-

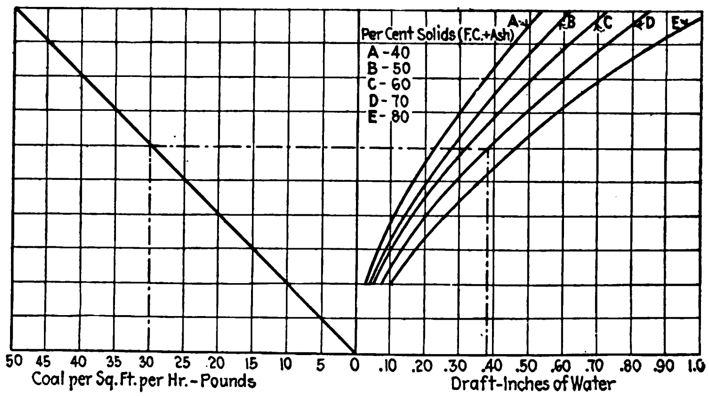


Fig. 59.—Furnace Draft Required for Natural Draft Stokers.

ably from the values given. The reason for this is that the curves fail to take into account two of the principal factors affecting fuel bed resistance, namely the dust and moisture

contents of the fuel. Commercial screenings will vary in size approximately as follows:

	Over 1"	Over ½"	Over ¼"	Over ⅛"	Through ⅛"
Maximum.......	50%	25%	15%	7%	3%
Minimum.......	2%	20%	25%	15%	38%

Hundreds of draft readings have been taken on tests where the combustion rates were being carefully recorded but no information has been secured as to the percentage of dust in the fuel. The relation of draft to combustion rate is affected to such an extent by the percentage of fine dust in coal that without this information the draft readings and combustion

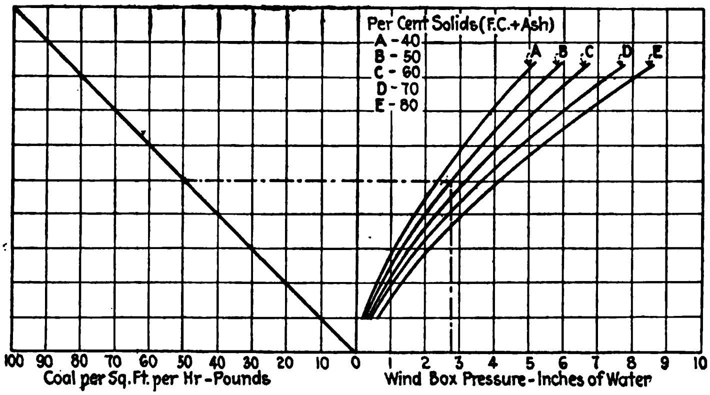


FIG. 60.—Windbox Pressure Required for Underfeed Stokers.

rates are of little value. A fuel containing 40% of dust that will pass through a ⅛" round screen can be burned at only about 60% of the rate which can be secured with the same draft from coal containing only 5 or 10% of dust. It is for this reason that such wide discrepancies exist in the drafts required to burn fuel.

It has been found that by adding a sufficient amount of moisture to agglomerate this dust, the fuel bed resistance can be materially reduced and the combustion rate with the given amount of draft correspondingly increased. This explains the improved combustion which often results from adding moisture to fuel and which is often ascribed to chemical action of the moisture. The action is entirely mechanical and is due to reduced fuel bed resistance.

The percentage of solids (F. C. and ash) in coal also affect the draft required for combustion. A coal high in volatile can be burned at a given rate with less draft than a low volatile coal, not because less air is required but because it is the solid matter and not the volatile that determines the character of the fuel bed and the amount of air that can be drawn in with a given draft. The curves (Fig. *59*) show to what extent this factor influences the draft required. As an example, a thirty-pound combustion rate with coal having F. C. + ash = 50% will require .27″ furnace draft while a

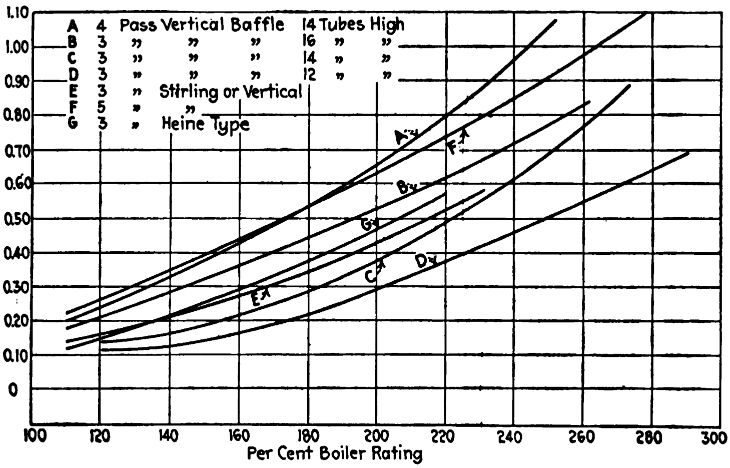


FIG. 61.—Draft Losses through Boilers.

coal having F. C. + ash = 70% will require .38″ draft for the same combustion rate.

Second: "**Loss through boiler.**" The draft loss through boilers varies through wide limits. With the great number of boilers of different designs and the variety of baffle arrangements, installed to meet particular local conditions, it is impossible to establish values for draft losses which can be of general application and it is advisable to secure from the manufacturer, figures for the particular boiler and baffle arrangements which may be under consideration.

The curves shown on Fig. *61* may be used, however, for preliminary calculations.

Third: "**Pressure required to create velocity of gases leaving the boiler.**" The draft required to create velocity of the gases leaving the boiler is not an important item. At a velocity of the 20′ per second, the draft required is about .05″ at a temperature of 550° and for 30′ per second, the draft required is about .11″. There is, however, a certain chimney effect in the boiler itself due to the vertical height from the fuel bed to the damper which is usually sufficient to offset the loss required to create the velocity. This is clearly shown in the case of some large boilers operating on forced draft running with practically atmospheric pressure in the furnace which can be operated at rating with atmospheric pressure or a slight pressure above atmosphere just below the boiler damper. In this case, the chimney effect of the boiler is sufficient not only to create the velocity, which is low, but also to overcome the boiler draft loss.

Fourth: "**Restriction at damper.**" There should be no restriction at the boiler damper if it were wide open but the areas through boiler dampers are often inadequate especially when the boilers are operated at high ratings. As dampers are often installed there is a sudden change of direction either when the gases enter the damper opening or just as they leave which is responsible for a certain amount of draft loss. When boilers are operated at high ratings, the gas velocity through the average damper will exceed 30′ per second and there will be a draft loss of about .1″. In many cases, however, dampers are installed in such a manner that the loss is two or three times this amount, due to the fact that the path of the gases through the damper opening is such that when the damper is wide open it interferes with the free flow of gases through the opening on both sides of the damper itself. The location of the damper and the path of the gases both entering and leaving should be carefully considered to insure a free passage if unnecessary draft losses at this point are to be avoided.

Fifth: "**Breeching losses.**" Accurate data upon which draft losses through a given breeching may be determined are not available. The effect of changes in cross section of the breeching, disturbances in the flow caused by successive boilers discharging into the breeching, the shape of the gas passage and

the nature of its surface cannot be determined with a degree of accuracy which permits of general application. The best posible guide in the design of a breeching is an accurate record of draft losses in a similar breeching where gas velocities are approximately the same as those for which the breeching is being designed.

There are a number of "thumb rules" for proportioning breeches in accordance with boiler H.P., grate area, or some other known unit, but they all neglect one or more factors which have an important bearing on the correct design. It is necessary, therefore, to analyze the conditions in sufficient detail to determine the gas volumes to be handled and the breeching areas proportioned to give the desired velocity.

Formula *A* (page 132) for friction losses in chimneys is applicable to breechings but is less accurate due to the disturbances created by successive boilers discharging into the breeching with consequent sudden changes in the direction and velocity of flow.

In general, it may be said that there will be a loss of .1″ for every 50′ of straight breeching for breechings having not less than 25 sq. ft. cross sectional area and a velocity not exceeding 30′ per second. The draft loss in a right angled bend will also be about .1″ for a velocity not exceeding 30′ per second. If the area of the breeching is small, the draft loss is increased and in such cases, it is usually preferable that the velocity be reduced rather than that the chimney be made high enough to overcome the additional friction. A good rule to follow in this connection is that the velocity in feet per second should not be greater than the area of the breeching in square feet. This of course becomes absurd for very small breechings but can be followed for areas as small as twelve to fifteen square feet. For larger breechings, a velocity of from twenty-five to thirty feet per second will be found satisfactory and this can be increased to thirty-five feet for short distances.

A circular breeching offers less resistance to the flow of gas than one of square or rectangular section. A breeching of a given diameter has about the same draft loss for a given condition as a square breeching whose sides equal the diameter of the round breeching. In the case of rectangular breechings,

the ratio of surface to cross sectional area is greater than for either the round or square breeching and the carrying capacity for a given draft loss becomes less. By the use of curve (Fig. 62) a rectangular breeching may be directly compared to its equivalent circular or square section of equal carrying capacity.

Sharp turns or sudden changes in cross section are to be avoided and a construction should be employed that is air-tight when new and can easily be kept tight. Suitable doors should be provided for inspection and cleaning and where

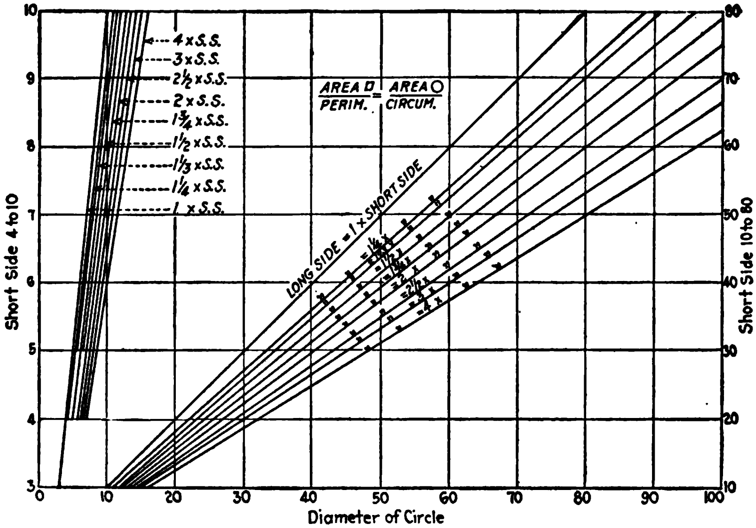


Fig. 62.—Circular Equivalents of Rectangles for Equal Friction per Unit of Length.

radiation will cause excessive temperatures in places where repair men may be required to work, the breeching should be insulated. Underground flues are almost invariably unsatisfactory and should be avoided wherever possible.

It is sometimes difficult to secure a simple straight breeching on account of local conditions but if the importance of such construction is fully appreciated, the necessary changes can usually be made to permit of a suitable layout. Construction difficulties are soon forgotten after operation has begun but the operating engineer who has to contend with a poor breeching, works at a disadvantage as long as the plant

operates. In one extreme case of bad design, two 90° turns and twenty feet of length were added to avoid moving a 16″ steam line which could be cut out over the week end and changed without affecting the plant operation.

Fig. *63* shows the method of analyzing draft conditions in a breeching and incidentally brings out some defects in the design shown although the areas were ample and the gas velocity at no point greater than twenty-five feet per second.

The dampers when open project into the breeching and seriously interfere with the gas flow both by restricting the

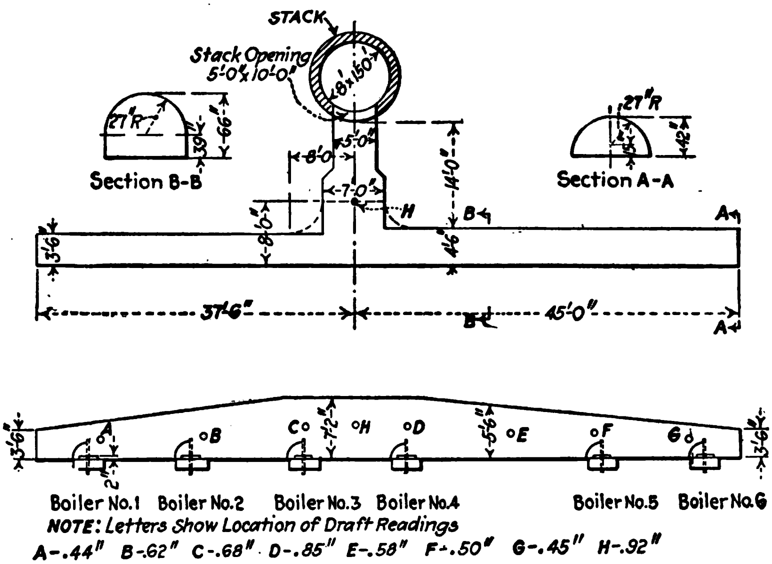


Fig. 63.—Analyzing Draft Losses in Breechings.

breeching area and by improperly directing the gas. At *A*, the gas passing through the left side of the damper opening is directed against the top of the breeching and must make a sudden change in direction resulting in an unnecessary draft loss. At *B*, the same condition exists and in addition, the net breeching area is reduced to about two-thirds of the full area, resulting in a gas velocity at this point considerably greater than that for which the breeching was designed. This condition exists at all boiler dampers and is a serious defect. Where the two branches meet and go to the chimney, there is a sudden

change in direction and a serious disturbance to flow by the manner in which the two streams of gas come together. This is shown by the large draft loss between points *C* and *H*. The sudden reduction in width between point *H* and the entrance to the chimney is also responsible for an unnecessary loss which could easily have been avoided.

This breeching would be a good design instead of a very poor one if the following changes had been made: First, raise the breeching enough to bring the top of the boiler dampers when wide open down to the bottom of the breeching, thereby allowing the full area for gas passage; second, eliminate the right angle turn where the two branches meet the connection to the chimney; third, reduce the width of this chimney connection gradually instead of suddenly. The changes could have been made with only a slight increase in cost and no structural difficulties would have been encountered in this particular case.

The sum of losses one to five inclusive, is the actual draft which must be available at the base of the chimney and when determining the chimney height necessary to produce this draft, the maximum temperature of the atmosphere in the given locality must be used because the draft depends not upon the temperature of the gases in the chimney but upon the difference between this temperature and that of the outside air.

There has been much discussion of the merits of individual chimneys as compared with one large chimney for several boilers. The individual unit has the advantage of being proportioned for only one boiler and no allowance must be made for leakage through dampers of idle boilers. Repairs can be made when necessary without interfering with plant operation, there is no breeching loss to consider and close fitting boiler dampers are not necessary. Where boiler units are small, however, the cost is excessive and this consideration will result in the selection of one chimney for a number of units. A similar selection is sometimes made for the sake of appearance. In general it may be said that while the chimney serving a group of boilers must be made higher to take care of breeching losses and damper leakage there are no controlling factors except cost and appearance.

The efficiency of a chimney will depend upon the basis on which the calculations are made. Since the flow of gases is maintained due to temperature difference inside and outside the chimney, the efficiency is measured by the amount of heat expended for this purpose. The foot pounds of energy required to handle a given weight of gas represents a very small percentage of the energy delivered to the chimney in the form of heat and on this basis, the efficiency would not exceed .06% under average conditions. While the actual efficiency is very low, the chimney has many advantages as a draft producer. It has no moving parts and does not require daily attention. The cost of upkeep is low and the possibility of failure is remote. The heat necessary to produce the draft has been rejected by the boilers and might be considered a waste product. With these advantages, the chimney would appear to be ideal for producing draft but the fact that other methods are often employed, shows that there are conditions which the chimney cannot meet.

Induced Draft.—With the draft requirements in many plants and the temperatures at which the gases leave the boiler heating surface, a chimney of less than 200′ in height is sufficient. Many of the smaller installations require chimneys of not over 100′ in height and except in unusual cases, chimneys of over 250′ are not built.

The use of an economizer has two very important effects on the draft producing apparatus: first, it lowers the temperature of the gases, and since the ability of the chimney to produce draft depends upon the difference of temperature between the air and gas, it reduces the effectiveness of the chimney, requiring a much greater height to produce a given draft intensity; second, the economizer offers a certain amount of resistance to the flow of gases which must be overcome by the chimney draft. A greater draft intensity at the base of the stack is therefore required when the economizer is used. Considering the decreased temperature and the increased gas resistance, it would often require a chimney 400 or 500′ in height to produce the necessary draft. This, of course, is impractical on account of the great cost and some other means for producing draft must be employed.

A number of years ago many installations were made in which one economizer served all the boilers in the plant and delivered the gases to a chimney. The installation of economizers under such circumstances often resulted in an actual loss in economy instead of in a substantial gain which should have been realized, and in addition, decreased the capacity on account of the large reduction in draft available for burning fuel.

The induced draft fan which takes the gases from the breeching at a pressure below the atmospheric pressure and discharges them to the atmosphere is commonly employed where the chimney is not able to meet the conditions. With this arrangement, any draft intensity required in even the most unusual cases is easily secured. Induced draft is also employed in many plants where a high chimney would detract from the appearance of the building or its surroundings.

The increasing tendency to operate boilers at higher ratings introduces two conditions tending to make induced draft desirable if not absolutely necessary: first, the temperature of escaping gases increases with the rating and it is found desirable to install economizers to reclaim the large amount of heat that would otherwise be lost; second, the draft loss through a boiler increases rapidly with the rating and at ratings now developed in many plants, chimneys of commercial sizes do not produce sufficient draft to overcome these high losses.

Induced draft fans to fulfill any set of conditions met with in practice can be selected from standard designs and it is therefore not necessary in the selection of induced draft equipment to go further than to determine the service which the fan must perform. The procedure so far as the suction at the fan inlet is concerned is practically the same as in the case of chimney design. To determine the volume of gas to be handled, it is necessary to know the maximum horse power which the boilers served by the fans will deliver, the heating value of the coal, the percentage of excess air in the gases entering the fan and the temperature. The percentage of excess air must be determined from a knowledge of operating conditions and the gas temperatures can be stated with a fair degree of accuracy by the builders of the boilers and economiz-

ers. With this information, Fig. *64* may be used to determine the cubic feet of gas to be handled per unit of time.

Induced draft fans are of two general types: the steel plate and multi-vane. Steel plate fans run at relatively low rotative speeds and are usually engine driven, the engines being direct connected. The multi-vane fans run at higher speeds and are suitable for turbine or motor drive. The type of fan selected will depend upon local conditions and individual preference. Where units of large size are installed, space limitations often

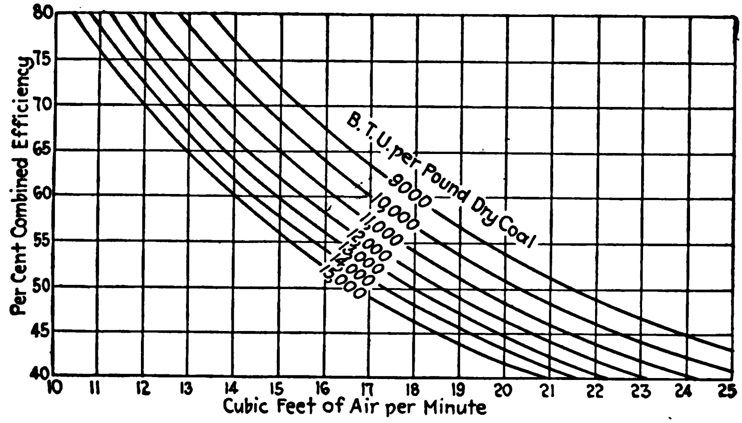


FIG. 64.—Volume of Air per Developed Boiler Horsepower.

make the multi-vane fan the only one which can be conveniently installed.

The fan drive must be selected with a clear understanding of the nature of the service it must perform and the drive should be of sufficient power to operate the fan at maximum capacity under the most unfavorable conditions. In the case of a steam-driven unit, the engine or turbine should be of sufficient size to carry the full load with an abnormal drop in steam pressure. When steam is low, the fan must handle the maximum amount of gas if normal pressure conditions are to be re-established and if the fan drive is not of sufficient power, the fan will slow down thereby crippling the entire plant. The drive should, therefore, be designed to operate on

a pressure somewhat below the lowest pressure which may ever exist.

The exhaust from the steam unit should be used for heating feed water or for other useful work around the plant. In case exhaust steam is not required, the fan should be motor driven. In the case of turbine drives, the fan may be direct connected to a low speed turbine if a large amount of exhaust steam can be utilized but where only a limited amount of steam is desired, the high speed geared turbine is preferable on account of its lower water rate. This matter should be carefully studied in connection with the heat balance of the plant and in no case should a steam driven unit be installed if any of the exhaust steam is to be wasted. If the exhaust is properly utilized, the net reduction from the overall efficiency of the boiler unit will be only a fraction of one per cent but if the exhaust is to be discharged to the atmosphere, the loss may be as high as five per cent.

A chimney which is properly designed for a given plant condition where economizers are not installed, would be unable to meet the requirements if economizers were added, due to the fact that it would not be able to produce sufficient draft intensity to overcome the various resistances. In the case of an induced draft fan, however, it usually is the case that the same fan will do the work whether economizers are installed or not. In either case practically the same weight of gas must be handled. The installation of economizers merely reduces the temperature and volume and increases the resistance to be overcome. The induced draft fan operating in connection with economizers would have a smaller volume to handle than would be the case without economizers and due to this decrease in volume, and increase in density the fan would naturally produce a higher suction. The one just about offsets the other and the fan is therefore able to meet both conditions, requiring almost exactly the same horse power in either case.

Forced draft is required for those stokers carrying heavy fuel beds and designed for operation at high rates of combustion. Pressures under the grates of such stokers vary from 1″ to 6″ and the increasing use of such stokers has brought about the development of a number of fans particularly well

suited to this class of work. The pressure required for different combustion rates on stokers using forced draft is subject to the same correction for the dust content of the fuel that applies to natural draft stoker work and (Fig. *60*) showing the relation of wind box pressures to combustion rates are approximate only although the effect of the dust content is less marked than in the case of natural draft stokers.

Where forced draft is employed it is necessary to make calculations of the amount of air that will be required. It is possible to calculate the theoretical amount of air required for combustion as outlined in Chapter I and to make an allowance for excess air entering the combustion process and for leakage from the air duct. Fig. *64* shows the volume of air in C.F.M. per boiler H.P. developed for various efficiencies and grades of coal. For example, if 13,000 B.T.U. coal were being burned at a combined efficiency of 70%, there would be required 12.8 cubic feet of air per minute per H.P. This allows about 60% excess air which is more than that required for good operation and will be found to provide ample for all reasonable conditions.

Forced draft fans should be selected of ample capacity for the maximum demand which they may be required to meet in case of emergency. The data available on forced draft stoker work indicate that in almost every installation, the limiting capacity is determined by the ability to force air through the fuel bed. In the case of natural draft stokers an abnormally high draft draws such quantities of air through the fuel bed near the zone of ignition that the temperatures will fall and ignition become sluggish, thus limiting the capacity which can be secured. Stokers of this type are therefore provided with arch constructions which are designed with a view to providing sufficient ignition effect for the ratings which are desired. In the case of the heavy fuel beds carried on forced draft stokers there is probably a similar limitation but it has never been reached in practice. The limiting factor is either the ability to supply air or to discharge the refuse and since for short peak loads the stokers can be operated without discharging refuse, the ability to supply air is the

limiting factor, and the importance of ample fan capacity is apparent.

In selecting a fan for high altitudes, the density of the air must be taken into account. The static pressure developed by a fan at any given speed will decrease with increased altitude and it is therefore necessary to make a correction as fan performances are based on sea level conditions. It is also necessary to correct the volume of air to give a weight of air equal to the weight at sea level. It will be found, however, that the power required to drive the fan will be less than that calculated for sea level conditions and an additional correction must be made for this condition. Fig. *65* can be

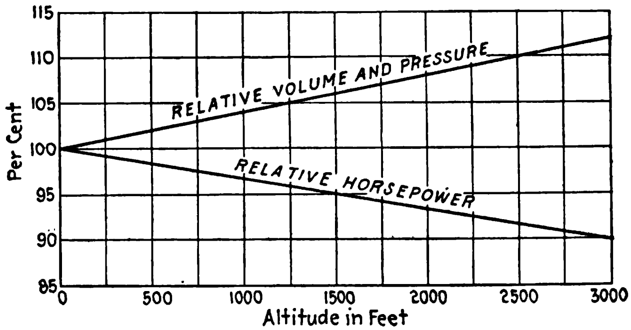


FIG. 65.—Altitude Corrections for Fan Performance.

used for this purpose. It will be seen that at an altitude of 3,000 ft. the volume and pressure determined for sea level conditions must be increased 12% and that the power will be decreased 10%. As an example, assume a condition requiring 25,000 C.F.M. at 6″ static pressure at sea level. At an altitude of 3,000′, the volume and pressure must be increased 12%, making 28,000 C.F.M. against a static pressure of 6.72 inches. If a fan were selected that would deliver 28,000 C.F.M. against 6.72 inches at sea-level and required 50 H.P. for its operation, the power required at an elevation of 3,000 ft. would be (.9 X 50) or 45 H.P.

A forced draft fan to be suitable for stoker work must have certain characteristics. Fans are designed to deliver a given volume of air against a given static pressure when running at a specified speed. In case the resistance be increased

and the speed maintained constant, some designs will deliver against this increased resistance only a small percentage of their rated volume. Such fans are evidently not suitable for forced draft stoker work. In case of careless operation, abnormally heavy fires may be built up increasing the pressure against which the fan must operate and the design should be such that the fan will operate against this increased resistance with only a slight decrease in volume. The steel plate fan has the correct characteristics for such performance and multivane designs have also been developed which fulfill this requirement very satisfactorily. There are multivane fans designed for different service which do not have this characteristic and they should not be used for forced draft service.

The selection of a fan drive depends largely upon local conditions. Where exhaust steam can be used, steam driven units are often installed. In the case of small installations where the pressure need never exceed three or four inches of water, the slow moving steel plate fan direct driven by a steam engine is often used. Larger installations usually consist of multivane fans turbine driven with or without reduction gears, depending upon the amount of exhaust which can be used. It is sometimes desirable to install some steam driven and some electrically driven fans in a large installation in order to assist in maintaining a correct station heat balance. In plants where exhaust steam can be utilized, the net charge against the forced draft equipment represents from .25 to .6 of 1% of the steam generated. Where motor driven fans are used, the net deduction will be from .75 of 1% to 1½% but will always be less than 1% where efficient generating equipment is installed.

Boiler units of 800 H.P. and larger, equipped with forced draft stokers, are suitably served by individual fans. This arrangement has the advantage of short connections from fan to stoker wind box and simplifies the regulation of the air supply to the individual units. It also eliminates the resistance which is encountered in long air ducts requiring less power to operate the fans. Smaller units are usually served from a common air duct suplied by one or more fans conveniently located. Owing to the fact that air is delivered to the stokers

at atmospheric temperature, ducts of large cross section are usually not required. Air velocities of from 30 to 50′ per second are usually employed, although in case of space limitations considerably higher velocities can be used if proper allowance be made for the friction in the duct. For steel ducts there will be a pressure drop equal to the pressure required to create the given velocity for every twenty diameters of duct and a right angled turn will cause a drop of one half this amount. For construction reasons, ducts are usually made square or rectangular and the equivalent round duct may be readily determined from Fig. *62*.

It has been pointed out that the plant heat balance affects the selection of fan drives. Another factor which must be considered is the nature of the boiler plant load. In the case of an electric generating station, any accident which affects the electrical system seriously will throw the load off the boiler house. In such plants motor drives can be safely employed but if part of the steam goes to the electric generating apparatus and a considerable amount goes into process work, a failure in the electrical ends of the plant will throw only part of the load off the boilers. In such cases, it is desirable either to install some steam driven fan units or to secure the necessary electric power from an independent steam driven house generating set.

CHAPTER VI

FACTORS AFFECTING SELECTION OF STOKER EQUIPMENT

When stokers are applied to steam generating apparatus, the individual features of the different types of stokers and their influences are taken into account. Especially is this necessary for proper selection of stoker equipment to attain certain ultimate results of the complete generating unit including the stoker, the furnace and the boiler.

A plan to investigate the stoker for a special combination requires primarily an exact definition of the terms used in connection with the units making up the complete steam generating apparatus. For example, the word "boiler," is employed indiscriminately to designate either the boiler proper or the combination of it with other apparatus.

The brick walls which enclose the boiler, the stoker or the furnace, are not recognized as being in any way a part of the metal structure.

The stoker is that portion of the combination which provides means for feeding the fuel as required, supplying the air in such relative proportions as to cause a balancing of the quantities of air and combustible, and causing the air and gases to mix and burn without smoke, also providing means for burning the coke and discharging the ashes.

The furnace is the intermediate element located between and connecting the stoker and boiler, wherein the process of combustion which begins at the grate is finished, and where a sufficient mixture between air and combustible may be secured.

In selecting stoker equipment, four factors are considered. These, in the order of their importance, are—

1. Load to be carried.
2. Fuel to be used.

3. Draft requirements.
4. Application characteristics.

LOAD CONDITIONS

The character of the load to be carried, that is, the boiler horse power that must be developed and the time element in connection with increases in the load, is of prime importance because this factor is generally beyond control; that is, the characteristic load is generally established by the particular industry. It is the function of the stoker and boiler unit to carry the horse power requirements through the many variations, at a minimum cost, and above all, in a reliable way.

The problem of a manufacturer who has a steady load and a comparatively continuous output of his product, is entirely different, insofar as stokers are concerned, from that of the Central Station operator who is called upon to meet almost instantaneous demands for steam which require operation of boilers at from 100% to 400% of boiler rating.

When the load that is to be carried is determined, a study is made of the characteristic curves of the different types of stokers showing the relation between the load and the combined efficiency of the boiler and stoker. Stoker performance follows quite closely a certain curve, and this varies according to the proportions of the apparatus.

Fig. *66* shows the relation between the coal burned and the combined efficiency of boiler and grate of an underfeed stoker. It has a wide range on each side of the peak of the curve, and is relatively flat.

A range in combustion rate of 3 to 1, and, in some cases, 4½ to 1, is possible on this type of stoker without decreasing the efficiency very much. This corresponds roughly from 70% to 200% of boiler rating for some sizes of underfeed stokers, and 70% to 300% for larger sizes. Fig. *67* shows the ability of the underfeed type of stoker to handle sudden demands for steam without very much preparation. Without forced draft, sudden changes in fuel-burning rate would not be possible. The deep fuel bed provides a reserved capacity so that jumps from 50% to 200% of rating can be made without much change in the fuel-feeding speed.

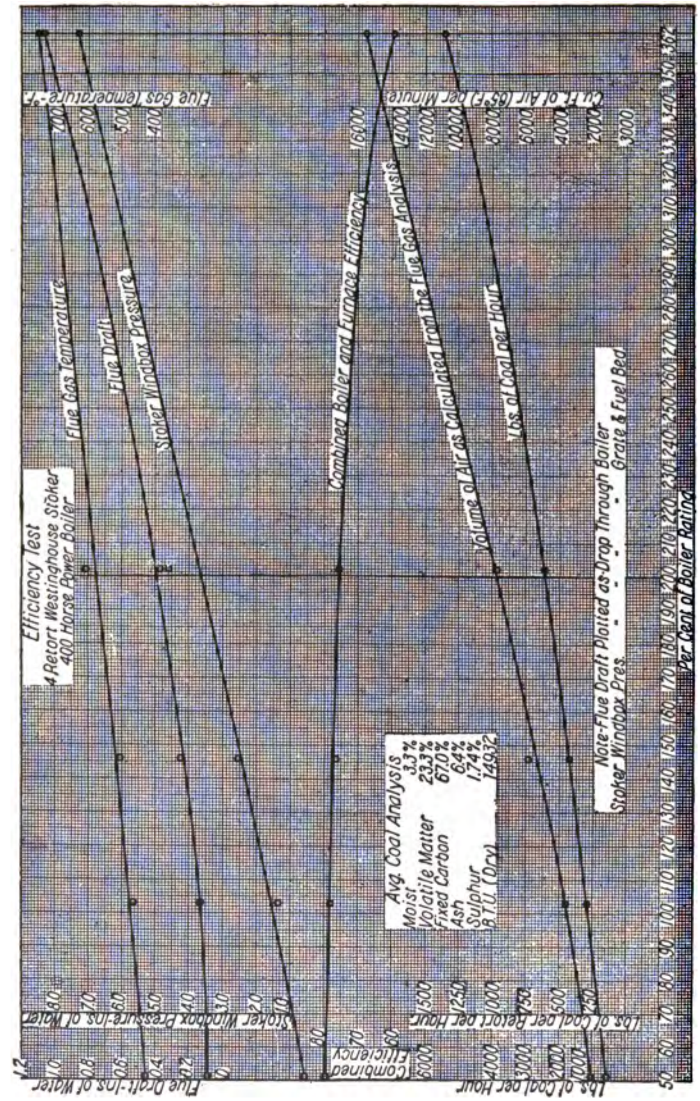


FIG. 66.—Relation between Load and Combined Efficiency of Boiler and Stoker of Underfeed Stokers.

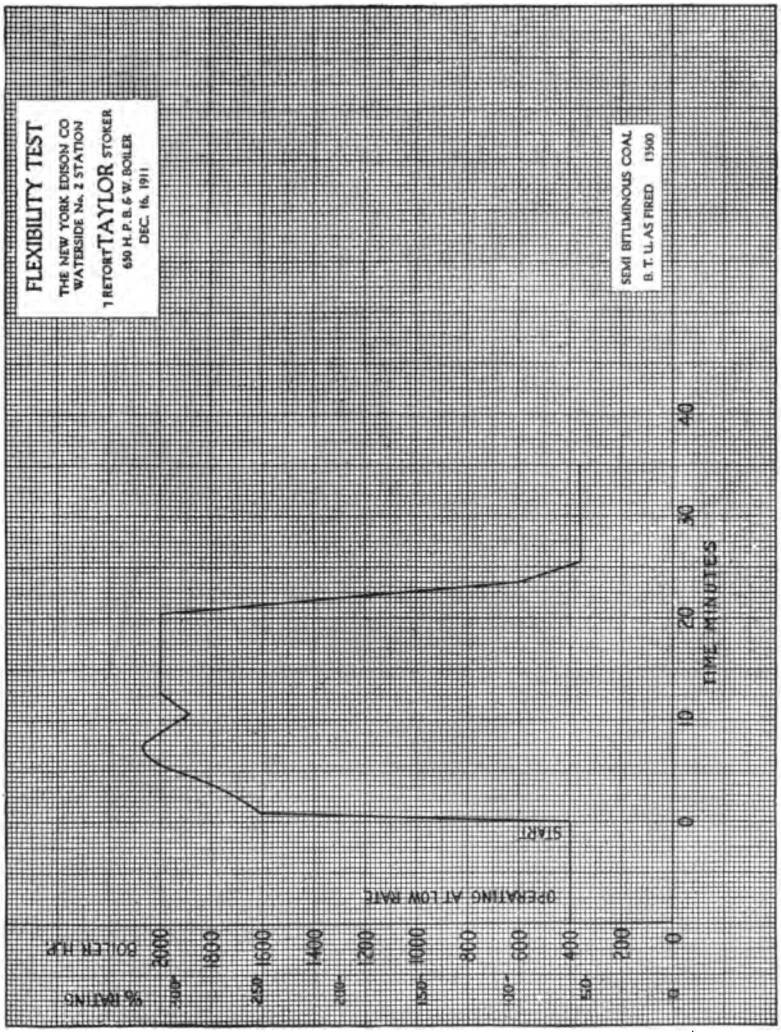


FIG. 67.—Flexibility of Multiple Retort Underfeed Stoker.

Fig. *68* shows the relation of load to combined boiler and stoker efficiency of the overfeed stoker. This characteristic curve has about the same shape as the underfeed but does not have the same range. The most efficient point for this condition was at 79% of boiler rating, and the maximum horsepower was 225% of boiler rating, which was probably the maximum reserve capacity for the local conditions under which the equipment was designed.

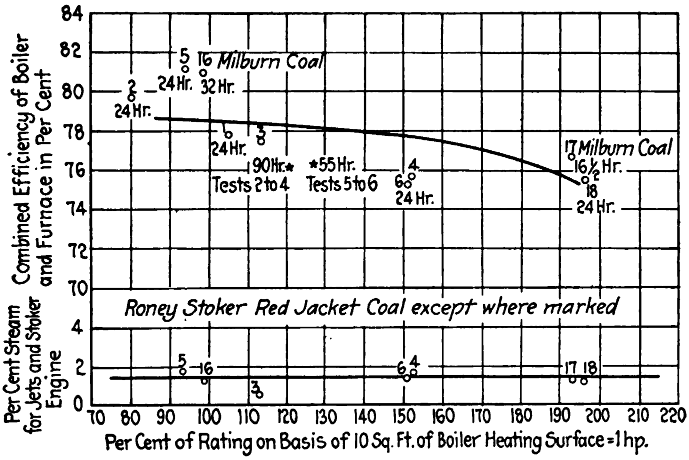
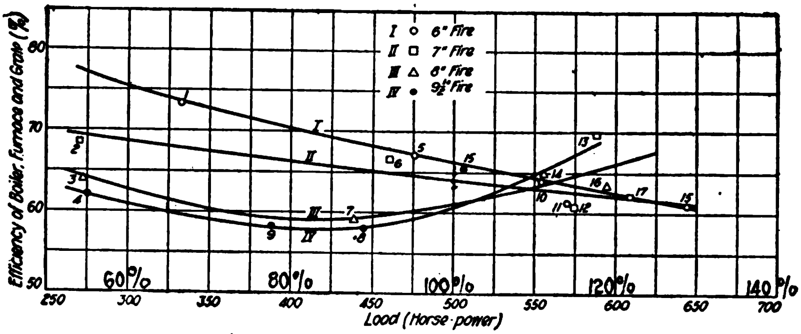


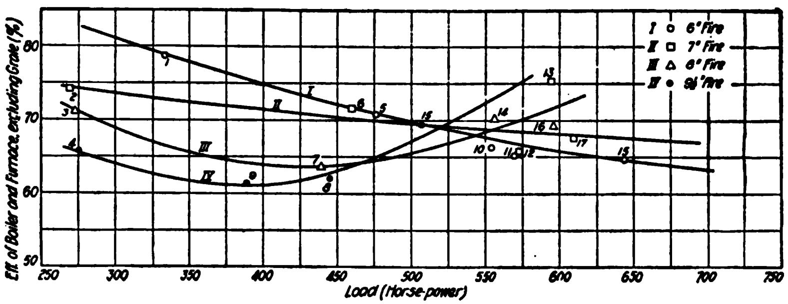
FIG. 68.—Relation between Load and Combined Efficiency of Boiler and Stoker, Front Inclined Overfeed Stoker.

Fig. *69* shows the relation of load to the combined boiler and stoker efficiency for different fuel bed thickness of the chain grate stoker. The chain grate embodies the automatic principle of ash disposal more completely than any other type, because coal is fed to a hopper in the front and ash discharged at the rear automatically. Both of these functions are performed by mechanical means, and it is for this reason that the characteristic curve drops off so rapidly at low ratings.

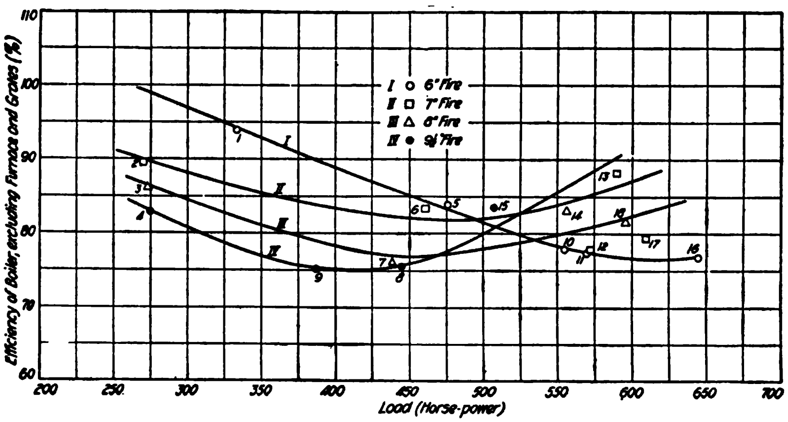
A chain grate stoker 10 ft. long, and feeding a fuel bed 6 inches thick to burn 25 lbs. of coal per square ft. of grate surface per hour, would require a speed of the grate of 2½" per minute. If the fire were carried thinner, a corresponding increase in the grate speed would be required, but, in any case, grate speeds of over 4" per minute, are unusual, and the wear



Relation between Load Efficiency of Boiler, Furnace, and Grate.



Relation between Load and Efficiency of Boiler and Furnace, Excluding Grate.



Relation between Load and Efficiency of Boiler, Excluding Furnace and Grate.

FIG. 69.—Efficiency Chain Grate Stoker.

and tear on the stoker at grate speeds of 4″ or over, is very rapid. When carrying a light load with the damper partly shut, the last two or three feet of the grate surface contains only a small amount of fixed carbon, and the fire is more or less dead at this part of the grate surface. If, in this condition, it becomes necessary to pick up a load suddenly, and the boiler dampers are opened wide, it is only a few minutes until the small amount of coke at the rear of the furnace is burned out, and there is nothing but dead ash remaining.

COAL CONDITIONS

The coals best adapted to the different types of stokers, in general, are pretty well defined in Chapter IV. For all coals having coking or caking tendency, that type of stoker so designed that it agitates the fuel bed and, in some cases, uses forced draft, is most suitable for these fuels. This takes in the front and side feed stokers, and some underfeed types. Coking coals must be agitated in order to obtain a thorough air distribution through the fuel bed. If coking fuels are not agitated, they ball up into large masses and the air admission is faulty because it only enters the fuel bed through the interstices between the large masses. The result is that a large percentage of carbon is dumped in the ash pit unconsumed. Most of the eastern coals are coking or caking coals, and it is for this reason that the front and side feed and underfeed stokers have been very successful in handling this kind of coal. There are, however, some eastern coals that do not require agitation when being burned, and in using this grade of coal, the stoker that agitates the fuel bed does not operate successfully.

For free burning coal, the chain grate type of stoker is most successful. This coal does not require agitation and, in fact, when it is agitated, it causes trouble on account of its high ash content. This is the most prominent characteristic of middle western coals, and it is for this reason that the chain grate stoker has been so successful with this fuel. The forced draft underfeed stoker, however, is burning this coal very satisfactorily, and on account of a better control of air

TABLE IV.

Fuel Bed Thickness, Inches	Coal Burned per Square Foot per Hour, 10′ 0″ Long Chain Grate Stoker. Grate Speed, Inches per Minute													
	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	7½
1	1.66	2.49	3.32	4.75	4.98	5.81	6.64	7.47	8.30	9.13	9.96	10.79	11.62	12.45
1½	2.49	3.73	4.98	6.12	7.47	8.71	9.96	11.20	12.45	13.60	14.94	16.18	17.43	18.70
2	3.32	4.98	6.64	8.30	9.96	11.52	13.28	14.94	16.60	18.26	19.92	21.58	22.24	24.90
2½	4.15	6.25	8.30	10.37	12.45	14.52	16.60	18.67	20.75	22.82	24.90	26.97	29.05	30.12
3	4.98	7.47	9.98	12.45	14.94	17.43	19.92	22.41	24.90	27.39	29.88	32.37	34.86	37.85
3½	5.81	8.71	11.62	14.52	17.43	20.33	23.24	26.14	29.05	31.95	34.86	37.76	40.67	43.57
4	6.65	9.75	13.30	16.62	19.95	23.27	26.60	29.92	33.23	36.57	39.90	43.22	46.55	49.87
4½	7.47	11.20	14.94	18.67	22.41	26.14	29.92	33.15	37.35	40.58	44.82	48.05	52.29	55.52
5	8.30	12.45	16.60	20.75	24.90	29.05	33.23	37.35	41.50	45.65	49.80	53.95	58.10	62.25
5½	9.13	13.60	18.26	22.82	27.39	31.95	36.57	40.58	45.65	50.21	54.78	59.34	63.91	68.47
6	9.96	14.94	19.92	24.90	29.88	34.86	39.90	44.82	49.80	54.78	59.76	64.32	69.72	74.28
6½	10.79	16.18	21.58	26.97	32.37	37.76	43.22	48.05	53.95	59.34	64.32	68.71	75.53	80.92
7	11.62	17.43	22.24	29.05	34.86	40.67	46.55	52.29	58.10	63.91	69.72	75.53	80.34	85.15
7½	12.45	18.70	24.90	30.12	37.35	43.57	49.87	55.52	62.25	68.47	74.28	80.92	85.15	91.38

admission, is presenting results, in overload capacities, that have not been obtained with chain grate stokers.

DRAFT CONDITIONS

The draft required for the different types of stokers varies according to the design. With underfeed stokers, the air for combustion is forced through the fuel bed by a blower so that the chimney need only to carry away the products of combustion. Side and front feed, and chain grate stokers, require draft in the furnace and over the fuel bed, necessary to pull the air through the fuel bed and then through the boiler.

Fig. *60* gives the pressure required in the wind box for multiple inclined underfeed stokers. Single retort underfeed stokers require from 1″ to 5½″ in the wind box.

Fig. *59* shows the draft requirement of the front and side feed stokers for different grades of coal. The minimum draft for this stoker should not be less than .2″ in the furnace, and the application of this stoker to old boilers should not be considered if the draft required to burn a given amount of coal is not available.

For chain grate stokers, about 10 pounds of coal can be burned per square foot of grate surface per each .1″ draft in the furnace. There should, however, be a minimum of .2″ available in the furnace and as high as .6″ for burning about 50 lbs. of coal per square foot of grate area. Fig. *71* gives the draft required for chain grate stokers when burning different kinds of Illinois coals.

APPLICATION CHARACTEIRSTICS

When stokers are applied to different types of boilers, the method of applying them differ. Stokers have individual characteristics that must be considered when the problem of furnace design is reached.

Chain Grate Stoker.—The chain grate stoker requires an ignition arch varying from 3′-6″ to 6′ in length, depending on the type of boiler and the grade of coal to be burned, the lower grade coals requiring the longer arches for their ignition. On account

FIG. 70.—Suspended Ignition Arch.

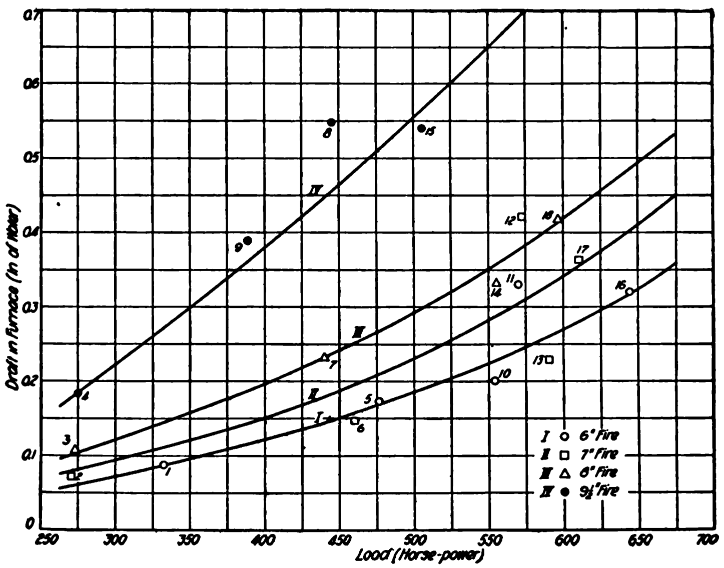


FIG. 71.—Relation between Load and Draft for Chain Grate Stokers when Burning Illinois Coals.

of the necessity for this ignition arch, and also on account of the length of the stokers usually installed, a furnace extension beyond the front line of the boiler wall is, in most cases, required. In some types of large Stirling boilers, not more than 18″ to 24″ is required. In the case of B. & W. and other vertically baffled boilers, this extension varies from 3′ to 5′. It is almost necessary to provide sufficient space in front of the furnace fronts, to completely withdraw the stoker from the furnace. It is, therefore, necessary to provide the proper distance in the firing space from the front of the furnace to the building wall or coal bunker. It is true that a great many chain grate stokers are installed in less space than this, but it makes repairs difficult and tedious when the stoker cannot be entirely withdrawn from the furnace for repairs.

Another characteristic feature of the chain grate which must be considered is that considerable coal fired sifts through the grates.

Where the coal contains only a small percentage of dust and sufficient amount of surface moisture to make the coal stick togther, the sifting is very low. On the other hand, where there is a large percentage of fine dust and the coal is dry, it is not uncommon to get considerable siftings. This falls through the lower part of the chain to a slab or pan located slightly below the floor. Where basement construction is installed, it is desirable to provide hoppers under the stoker chains in which siftings can be collected and returned by means of conveyor, or otherwise, to the coal bunkers.

Since the ash is deposited at the rear of the stoker, it is best to install an underground pit or tunnel, or provide a drag to pull the ash to the front, or where it can be readily handled.

To protect the links of the chain at the rear where the ash is discharged from the furnace, an overhanging self-supported firebrick wall is provided, or a firebrick wall supported on a water cooled pipe, commonly called a water back. This water back, or firebrick wall, is set at the proper height above the chain to permit the free discharge of ash. If the brickwork is allowed to burn off or become broken off, a considerable amount of air leaks around the rear of the stoker into the

furnace. If the water back is supplied with water from a cold water supply, considerable heat is lost unless this water is returned to a hot well. To overcome this loss, it is best to connect the water back into the boiler circulation and under boiler pressure. This construction is generally recommended.

Side Feed Stoker.—Side feed stokers present some problems in their application on account of peculiar construction features. Since the coal is supplied at both sides of the stoker and the coal magazine runs from the front to rear, it is sometimes difficult to get coal to the rear of the coal magazine. There are two ways in which this can be done. Either set the stoker in a full "dutch oven" so that the rear of the magazine comes in front of the front wall of the boiler, or have the boilers set singly so that the coal can be supplied to the coal magazine from the sides. If installations do not provide either one of these conditions, it is necessary to admit coal to the front part of the coal magazine and push it back to the rear with a bar, or by mechanical means. The entire grate area is covered by a firebrick arch, either supported from structural work or sprung arch shape and supported by skewbacks.

Ash disposal is not a serious matter since a grinder is usually located at, or slightly above, the floor line and the ash can be deposited in a small pit and raked into a conveyor or brought out on the floor and shoveled into wheel barrows.

The siftings of coal through the grate surface is not serious if the coal contains only a small percentage of dust and the grate bars are kept in first-class condition.

Since a full "dutch oven" is required, this means a long furnace extension and provision is made for sufficient space in front of the furnace fronts for proper operation.

Front Feed Stoker.—Front feed stokers are built on a considerable incline, and all depend, to a greater extent, on the force of gravity for movement of the fuel bed. Stokers of this kind generally employ a dumping grate and also use a fuel guard of some kind to prevent the fuel from dropping into the ash pit when the dump grates are dropped. When the dump grates have finally been cleaned and are brought back to their operating position, the guards are then lowered and the fuel bed moved downward.

This type of stoker does not, due to its construction, require an extension furnace, but in obtaining a proper furnace design, an extension might be necessary.

Ordinarily, the stoker hopper is 6′ or 7′ from the floor, and if coal is to be shoveled into the hoppers from the floor line, the stoker front is depressed so that the top of the hopper is not over 5′ from the floor line.

Ashes can be raked out into a pit at the front of the stoker and from there shoveled into wheel barrows. The best arrangement, however, is to provide hoppers underneath the dumping grates and remove the ashes by cars or conveyors in a tunnel below the boiler room floor.

The arch construction used with this type of stoker is very important. In general, it may be said that the ignition arch, or arch placed directly over the front part of the stoker, should be not less than 5′ long in order to secure proper ignition of the particular fuel to be burned.

Underfeed Stoker.—The multiple retort underfeed stoker is generally applied to boilers only in battery or single settings with alley-ways at least 8 ft. wide, so that access to the furnace can be made either at the sides or at the rear.

High speed forced draft fans are used with underfeed stokers, and these are located in a place where they are accessible and easily cleaned. Care is generally taken not to place them in a dark corner where it is difficult to get at them.

There should also be a sufficient supply of air for the fans if they are placed in basement. Often there is not sufficient air connections between the basement and the outside air to provide the air required.

The line shafting used to drive the stoker is also best placed above the boiler room floor, if possible, so that attention can be given to oiling and maintaining the bearings.

The design of ash pits for underfeed stokers requires special consideration. When operating at high ratings, the pits must be of sufficient volume to hold a reasonable supply of ash and refuse. They should also be air-tight and provided with doors. When the stoker is cleaned, if open pits are used, spark from the dropping ash is liable to injure the attendants. The doors on the ash pits should be of sufficient area so that ash can be

taken from the pits without difficulty. An underfeed stoker requires roomy ash pit facilities, and is not adapted to applications where these facilities cannot be procured.

On account of the high temperatures of underfeed furnaces, i.e., from 2500° F. to 3000° F., the very best firebrick should be used.

Arches are not generally used with underfeed stokers when applied to boilers where the proper setting can be obtained.

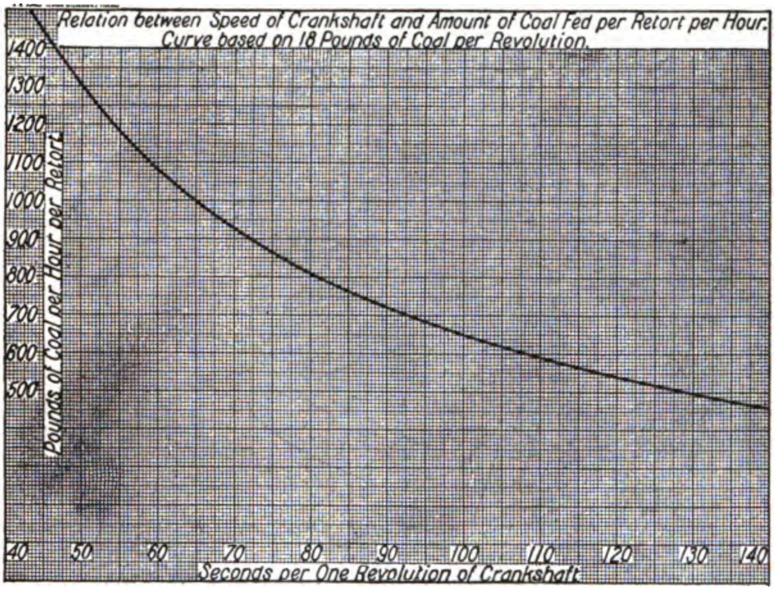


Fig. 72.—Relation between Speed of Crank Shaft and Amount of Coal Multiple Retort Underfeed Stokers.

Each feeding ram will displace from 13 to 18 pounds of coal per stroke, depending upon the size and kind of coal, therefore the approximate amount of coal used can be determined by the number of strokes multiplied by the number of rams or retorts per stoker. The approximate weights are 13 lbs. for lignite coal, 16 lbs. for western coal and 18 lbs. for eastern coal.

With some types of the underfeed stoker, dumping grates are used for discharging ash and clinker. These dumping grates are either operated by hand; mechanically operated by

steam and hydraulic cylinders; or an electric motor. It generally requires 45 second to 1½ minutes to operate these dumping grates, depending upon the type installed and the character of the fuel.

For higher ratings over long periods, a continuous method of ash disposal is sometimes used in the form of rotary clinker grinders. These have been applied to large stokers installed under boilers rated at 1500 H.P. and above.

Single Retort Underfeed Stoker.—The single retort underfeed stoker with side grates generally does not require ignition arches unless the furnace design makes such a connecting medium advisable.

With reference to the disposal of ashes, inasmuch as the accumulation of ashes is at the sides of the stoker, the same is accessible from the fire doors in the stoker front. The dumping grates are manually operated from the front and the ash discharged into the low ash pits at the side of the stoker. This ash can be raked to the front of the stoker and shoveled in the wheel barrows, or hoppers can be provided underneath the dump grates and the ashes taken out from a tunnel below the floor. Almost everything in connection with this type of stoker is accessible from the front, so that it presents no exact requirements insofar as accessibility at the sides or the rear of the stoker is concerned.

FURNACE DESIGN

The real economy in boiler rooms comes from good judgment used in making the combination of various boiler room apparatus fulfill their proper function. The individual characteristics of stokers have been given first, because the designing of furnaces require first the knowledge of the individual features of stokers.

Brickwork and Arches.—A furnace arch is made of refractory material and forms the roof of a furnace, or it is an arch located within the furnace for the purpose of aiding combustion. The combustion or ignition arch used for chain grate stokers is given considerable attention, because it has been found that the burning of different kinds of fuel depend to a great extent on the length of these arches and their height above the fuel bed.

In the chain grate type of stoker complete combustion of coal involves series of events, which can be briefly outlined as follows:

The fresh fuel, containing some moisture, enters the furnace where it is subjected to the influence of the furnace temperature. The moisture is first driven off, which is accomplished by the time the temperature of the particle of coal under consideration reaches the temperature of 212° F., and as the temperature continues to increase, the volatile constituents begin to come off. If the temperature at the point of ignition is sufficient, these burn in the space above, and approximately as fast as they are distilled. The burning of this portion of the fuel forms one source of the heat required for the ignition of the succeeding charge or unit of fresh coal.

The volatile contents are not all driven off at the same temperature, so this portion of the process continues during an appreciable time or until the fuel has traveled some distance in the furnace.

Temperature readings taken at the point of ignition indicate that about 1100 deg. must be obtained before the volatile will properly ignite and 1300 deg. must be had if the ignition is to be prompt and bright.

About the time that the volatile is all gone the particle of coal has reached a quite high temperature and the fixed carbon begins to burn.

It is obvious that this particular stage must be begun as early as possible, in order that the end may be within the time limit of the chain-grate travel.

Early and rapid ignition, therefore, by means of an arch, becomes, as a consequence, vitally necessary to the proper completion of the entire process.

With an arch having the front end 10 in. from the surface of the grate and elevated to 34 in., the ignition is slow and the coal will pull several inches away from the gate at the front of the grate before burning, thus losing the effect of a portion of the grate surface. Many experiments in suspending the arch for the purpose of getting ignition close up to the gate have been made, and found that by having the arch more nearly horizontal and elevating it more at the front, the coal

will take fire right at the edge of the gate. The effect from the arch suspended in this manner is probably due to decreasing the opening at the back end of the arch, thus holding the fire towards the front, and to increasing the opening at the front and reducing the velocity of the incoming air at this point.

In addition to producing quicker ignition, this arch adds to the capacity of the boiler.

An ignition arch for an overfeed stoker, when fuel is fed from the front, is made, generally, so that the crown of the arch is horizontal. The length of the arch depends considerably on the type of boiler and the extension of the stoker in front of the boiler. For Eastern coals, the arch is generally made about 4′ long—the stoker front extending in front of the boiler about 3′. As the gases move along the underside of this arch, it is well to have sufficient combustion space above the rear end of the arch so that there will be some travel for the gases to complete combustion before they reach the cold surface of the boiler, such as shown in Fig. *73*. When sufficient height cannot be obtained and the proper distance allowed between the grates and the cold surface of the boiler, a longer arch is used, such as shown in Fig. *74*. These arches are sometimes made of the suspended type where special firebrick blocks are suspended from supporting structure over the stoker, each block being suspended independently. In this design arch, the difficulty with expansion and contraction of the refractory material have no deteriorating effects. The sprung type of arch, as shown in Fig. *73*, is often used where the arch is made of standard square and wedge firebrick, and the skewbacks supported by means of structural angles set in the side walls. Proper buckstays are provided so that the skewback angles cannot move outwards.

First grade firebrick is generally used throughout the furnace setting. Firebrick in the side walls are placed 9″ headers, 18″ above the grate line, and above this line every fifth course is a stretcher course and tied in with the red brick.

The furnace arch, which is also an aid to combustion, is used with the double inclined side feed stoker. This arch is

either made of the flat suspended type or the sprung type supported by skewbacks.

The design of the multiple retort underfeed stoker is such that ignition or furnace arches are not used. Straight front, side and bridge walls are designed wherever it is possible to do so. Considerable trouble has been experienced with the brick

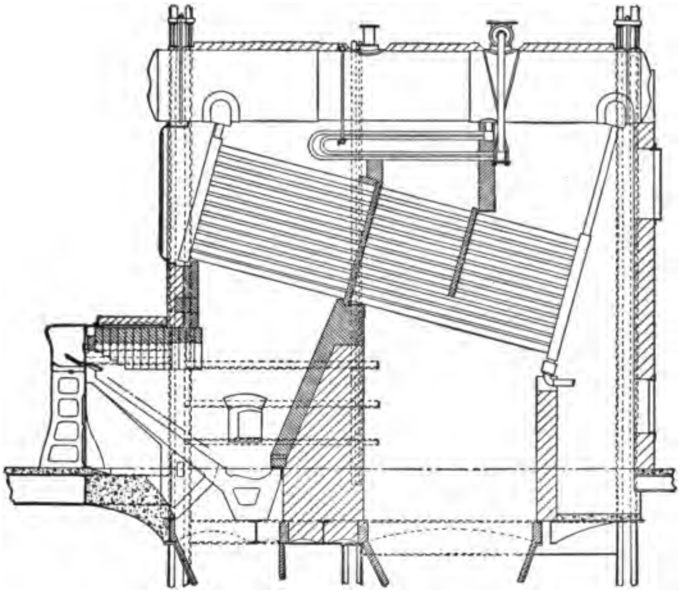


FIG. 73.—Overfeed Stoker Applied to B. & W. Boiler, Showing Extension of Furnace in Front of Boiler.

lining of the front or bridge walls due to the fact that they bulge out and eventually fall into the furnace. The front wall immediately over the throat opening of the stoker is constructed as shown in Fig. *94*. The brickwork in the furnace, in general cases, is made of 9″ firebrick lining, and, in some cases, 13″ firebrick is used.

If it is necessary to use arches, they are either of the sprung or suspended type, and, where very high ratings are expected, arrangements are made to place a slight pressure over the arches so that air is pulled from the outside into the

furnace instead of having the flames lap backward between the blocks of the arches.

Location of Observation Doors.—It is always necessary to obtain complete observation of furnace conditions, so that, with the multiple retort underfeed, the front feed, and chain grate types of stokers, it should be made possible to install one door at

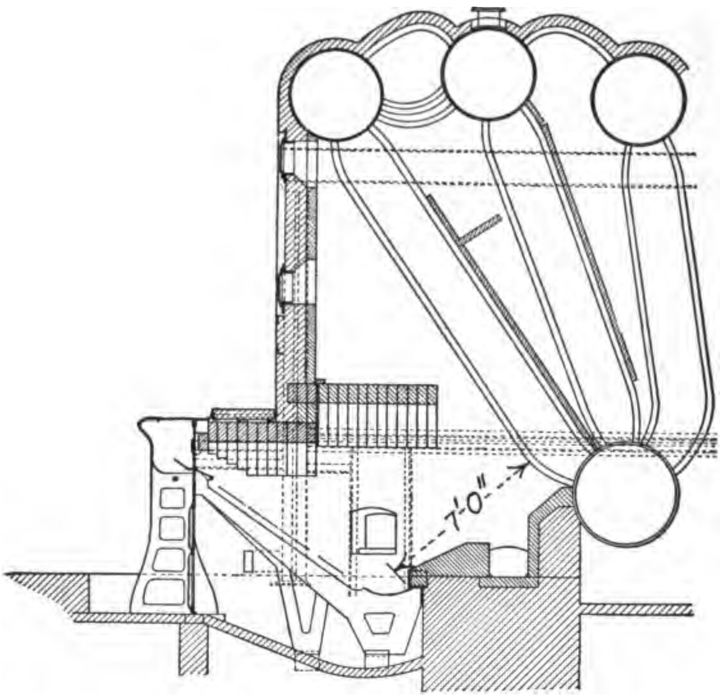


FIG. 74.—Stoker and Boiler Application, Showing Distance Required between Dumping Grates and Lower End of Tubes.

least in each side of the furnace. Stoker installations, where it is not possible to do this, make operation very difficult. One door should be placed near the throat opening where the fuel enters the furnace, and the other placed near the ash disposal mechanism. With large furnaces, observation door (Fig. *85*), located in the bridge wall, are very convenient.

Clinkering of Coal.—The formation of clinker at the side walls of furnaces and the difficulty of removing them when formed

is one of the most troublesome experiences of stoker operation, besides being a serious factor in high maintenance cost on settings. To reduce trouble of this kind, cast-iron air boxes have been built into the side walls of the furnace. A 4-in. pipe is connected to one of the air boxes, which are all connected together. Into this 4-in. pipe a $1\frac{1}{4}$-in. steam line is led to act as an inspirator; the steam jet, discharging into the 4-in. pipe, draws air into

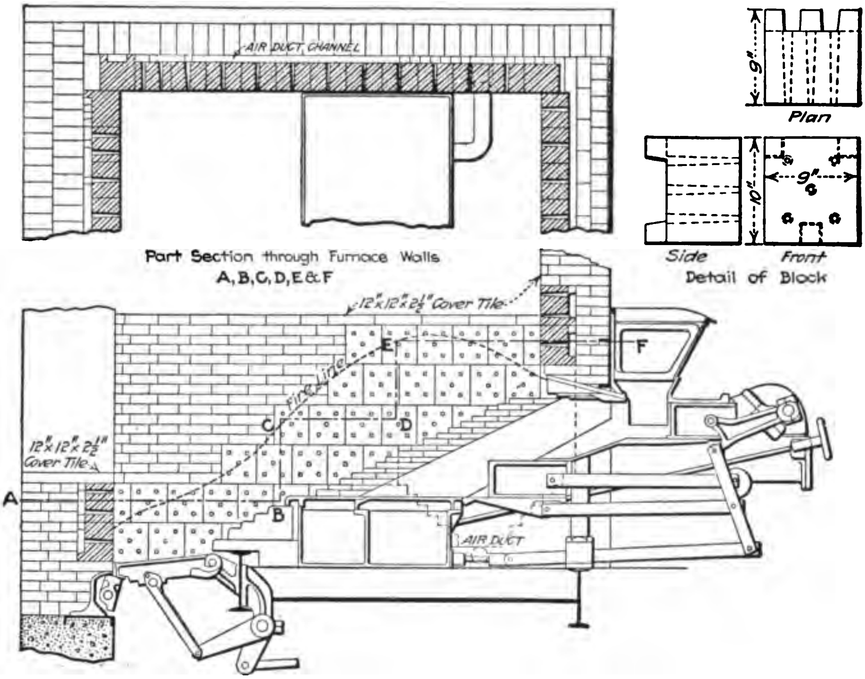


FIG. 75.—Application and Details of Drake Furnace Blocks.

the open end of that pipe. Three-quarter inch holes are drilled into the side of the box facing the furnace.

To prevent the formation of clinkers on the side walls of furnaces a method has been used consisting of an arrangement of firebrick in the furnace walls whereby air is admitted into the fuel bed between the bricks of the side setting. By supplying forced draft through these air passes, the face of the brick in the furnace wall is kept comparatively cool, the idea being that the clinker will not then adhere to

the brick surface. The combustion at these points is stimulated and increased.

Where forced draft is applied to the fires, a branch conduit is connected to the air passage back of the side walls and the same forced draft is applied through the brick spaces in the side wall.

The circulation of air passing directly into the fire from the furnace walls supplies draft at a point where it seems to be needed. A damper or valve operated from the outside con-

FIG. 76.—Interior View of Stoker, Showing Side Plates for Prevention of Clinker Adhesion to Side-walls.

trols the amount of air thus supplied. No more forced draft is used than that supplied to the fire through the grate.

In some cases steam jets are installed along the side tuyere boxes of underfeed stokers. This steam tends to rot the clinker so that it is more easily removed from the side walls.

Specially designed firebrick blocks are sometimes installed in the side walls of the furnace and arranged for air to enter the furnace through these blocks. This system is shown in Fig. 75.

Where the furnace will allow it, very often side plates are

used next to the retorts of the stoker, as shown in Fig. 76, which serves to keep the fuel bed away from the walls.

The accumulation of clinker on the bridge walls of underfeed stoker installations is partly overcome in the design. In one case the stoker is equipped with dump grate operating mechanism that is designed to knock loose the clinker adhesion from the bridge wall. This method as used, is shown in Fig. 77. High and low pressure water backs are also sometimes placed in the bridge wall to overcome the adhesion of clinker.

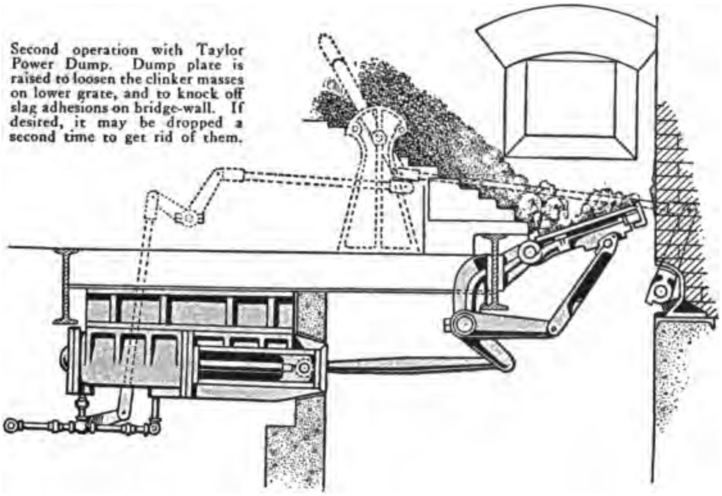


Fig. 77.—Dump Grate Operation Designed to Loosen the Clinker Adhesion from Bridge-wall.

Another scheme is shown in Fig. 78, where a series of tubes is set into the lower part of the bridge wall to assist in drawing heat from the ashes and preventing the clinker formation. These tubes are made to extend out through the bridge wall and connect to headers.

In some designs of the front inclined overfeed type of stoker, where clinkering coal is used, the exhaust steam from the stoker engines is used in connection with steam jets placed under the grates similar to that shown in Fig. 79. The small holes in the steam outlets are directed downward and the

draft pulling the steam up through the fuel bed tends to moisten and break up the clinker formation.

The dump grates of this type of stoker are supported in such a manner that, when the ash and refuse is dumped, the rear part of the dump grate travels through an arc and tends to pull the clinker away from the bridge wall (Fig. *80*).

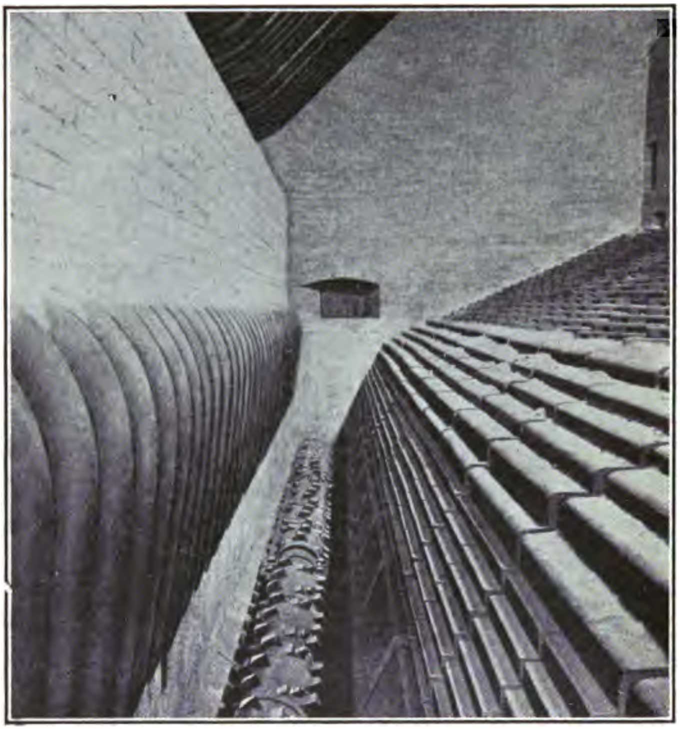


Fig. 78.—Water Tubes Set in Lower Half of Bridge-wall to Prevent Clinker Formation on the Wall.

Air Over the Fire.—The Bureau of Mines, U. S. Geological Survey, have shown that air taken through ordinary hand-fired grates is completely used up and the oxygen in the air combined with the carbon in the coal before it has a chance to get entirely through the fuel bed. Although this is not exactly similar to stoker fired furnace operation, on account of the more even distribution of air, nevertheless with certain high volatile coals,

even with some stokers, air over the fire is necessary. This has been accomplished in many cases by taking air from a channel built in the front wall of the stoker, as shown in Fig. *81*.

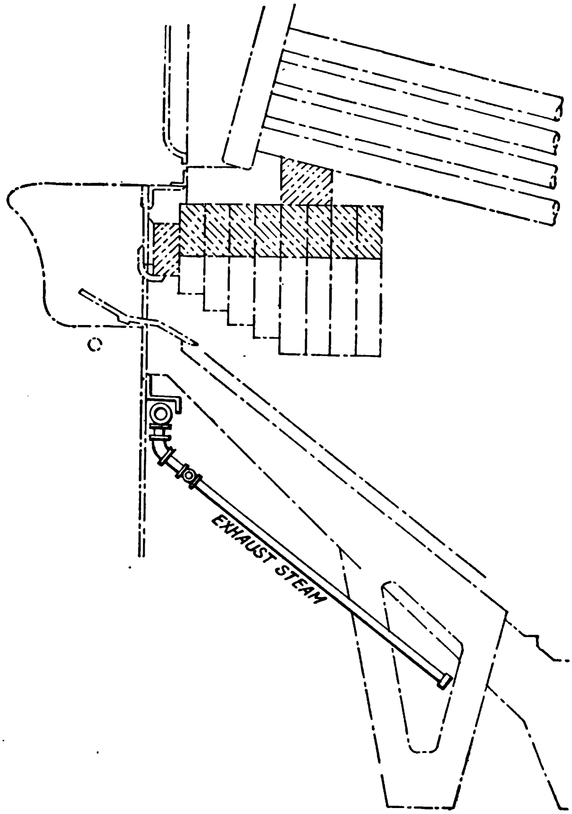


Fig. 79.—Steam Jets Placed under Stoker Grates to Assist in Loosening Clinker Formation.

Mixture of Gases in the Furnace.—In order to obtain an intermingling of gases in the furnace to complete combustion at the earliest possible time, steam jets are installed at the front of the front inclined overfeed stoker and three or four jets of steam sprayed into the volatile gases, as they are distilled from the fuel bed (Fig. *82*). These jets of steam tend to mix the gases with air coming down through the channels in the front

of the stoker, and is so designed to mix the gases in the furnace and complete combustion before the gases reach the boiler tubes.

Ash Pit Construction.—The design and construction of ash pits for underfeed stokers is very important so that the entire installation will not be limited as to the amount of ash and refuse that can be stored or removed in a certain time. For proper size of ash pits, etc., basements under underfeed stokers should be at least 20 ft. high. This will then give ample room for installation

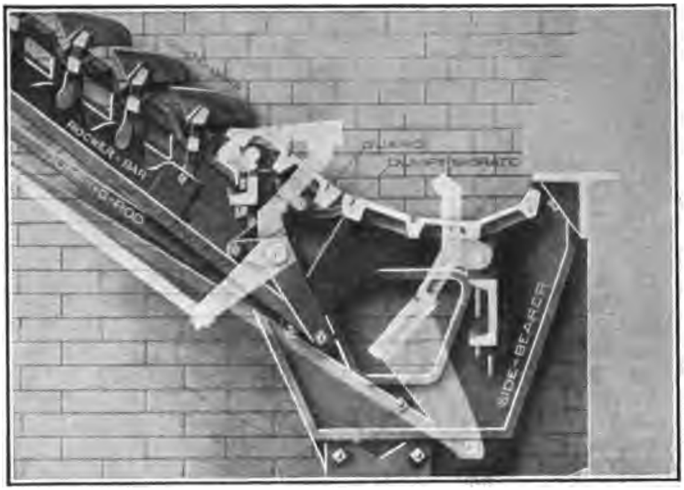


FIG. 80.—Dumping Grate and Guard of Overfeed Front Inclined Stoker, Showing Method of Breaking off Clinker Adhesion to Bridge-wall.

of fans, ash hoppers, ash cars and air ducts. Such a basement is shown in Fig. *89*.

Draft.—The maintenance of brickwork in an underfeed furnace becomes increasingly difficult with low draft pressure. The result of low draft in an underfeed furnace is to start a puddling condition in the furnace which directs the flames back into the cracks in the brickwork. In one installation, experiments demonstrated that, by pulling the gases through the boiler at a higher velocity, the capacity of the boiler was increased from 80,000 lbs. of steam to 120,000 lbs of steam. In the first instant, considerable trouble was experienced with firebrick, and after the draft was increased and the gases

pulled through the boiler and from the furnace at a higher velocity, this trouble ceased.

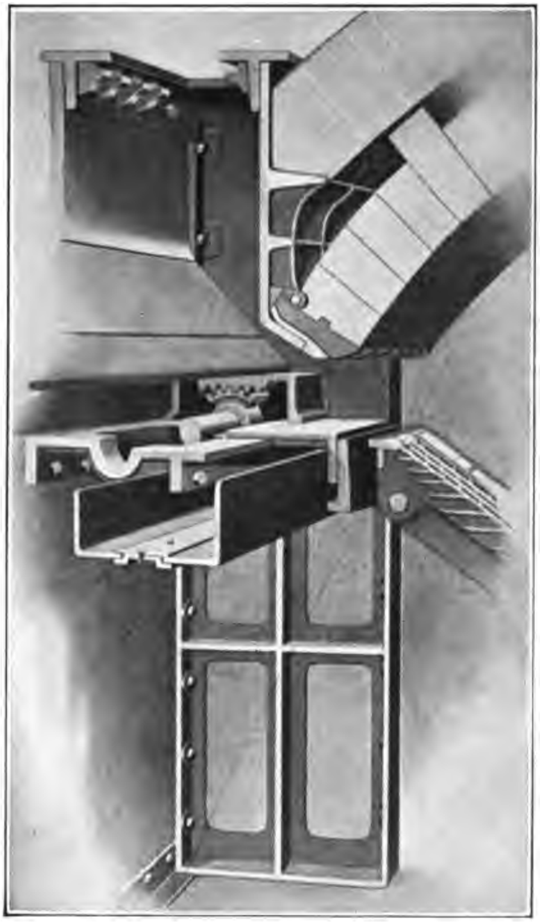


FIG. 81.—Magazine Construction, Showing Method of Admitting Air over the Fire in "V" Type Overfeed Stoker.

COMBUSTION SPACE

Underfeed Stokers.—Considerable effect is realized from the incandescent fuel bed of an underfeed stoker fire. For the same rate of combustion, the same combustion space is not required for this type of stoker, compared with other types. On account, how-

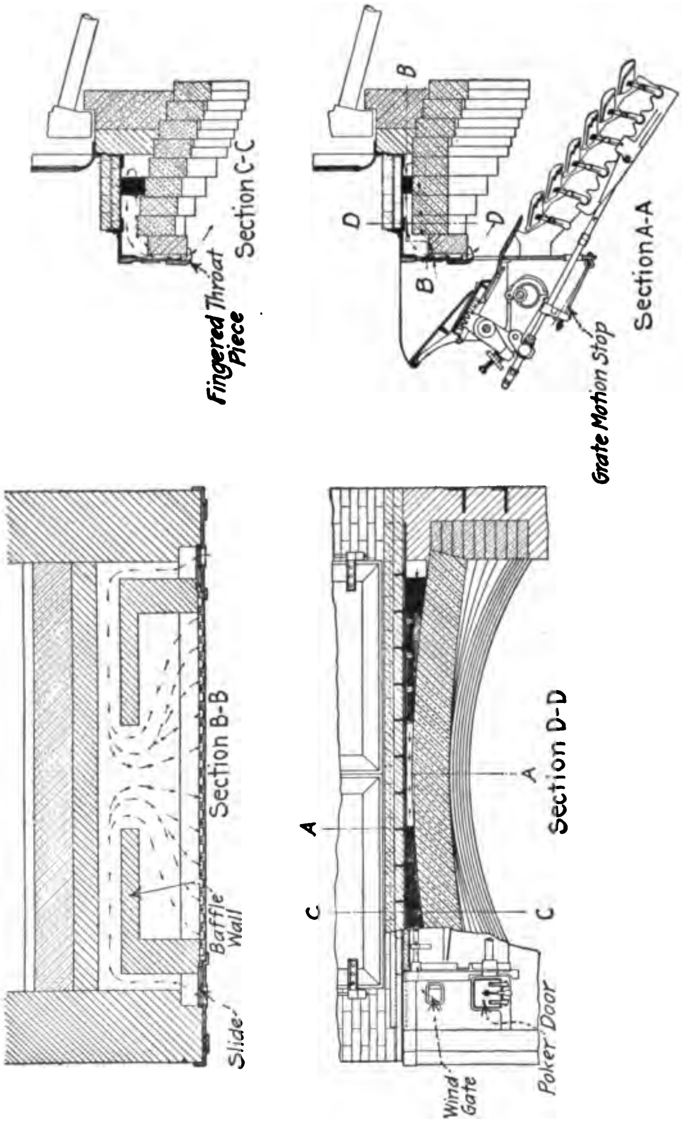


FIG. 82.—Method of Admitting Air over Fire for the Front Inclined Overfeed Stoker.

ever, of the fact that higher rates of combustion are possible, and generally used with this stoker, the combustion space should be as much as is required for other types of stokers. For Eastern Bituminous coal not less than 10 cubic ft. combustion space should be used per sq. ft. of grate surface, when a rate of combustion does not exceed 75 lbs. of coal per sq. ft. of grate surface per hour. For Pittsburgh, Illinois and Middle Western coals, at least 12 cubic ft. of combustion space should be used. This would require setting B. & W., Heine and similar types of boilers, from 10′ to 14′ from the floor line to the front header. When this stoker is installed in connection with the Stirling, Connelly, Ladd, Erie City or similar types of boilers, the dump grates of the stoker should be not less than 7′ from the tubes where they enter the lower drum.

Front and Side Feed Stokers.—For Eastern Bituminous coal, the front inclined overfeed stoker, should be set with at least an extension of 4′ in front of the boiler, with an arch at least 5′ 6″ long. When this stoker is combined with the B. & W., Heine and similar types of boilers, the front headers should be set 11′ from the floor line. For Pittsburgh, Illinois and other high volatile coals, this stoker should have an arch at least 7′ long with the stoker extended 5′ in front of the boiler. The front header of the B. & W., Heine or similar type boiler should be set at least 12′ from the floor line for this stoker. For the Stirling, Connelly, Wicks and similar types of boilers, the dump grates of this stoker should be at least 7′ from the tubes where they enter the lower drum.

For the side feed stokers, on account of the Dutch Oven extension, considerable combustion space is obtained by the mere construction of this stoker, but there should be at least 6′ from the rear grates of this stoker to any boiler tubes. The reason for this, is that there is green coal fed to that part of the grate surface nearest to the boiler and there should be sufficient flame travel from that part of the grate surface to the tubes of the boiler.

Chain Grate Stokers.—Chain grate stokers have been used more than any other in connection with Middle West High Volatile coals and for this reason, considerable development work has

been done in connection with the combustion space when this stoker is applied to different types of boilers. As previously outlined, the arch in connection with the furnace design of this stoker has considerable effect on combustion, and naturally this effects the type of combustion chamber required. When burning Indiana coals the furnace volume should be from 11 to 15 cubic ft. per sq. ft of grate surface. Arches varying from 4′ to 6′ in length, are also used as a factor in designing the combustion space. When burning Iowa coals, the combustion space and length of arch, is again of great importance, since the poorer grades of coal, as hereinbefore mentioned, are of low heat value and therefore difficult to burn. These coals require an arch covering ⅔ of the entire grate surface, and there should be provided at least 12′ between tubes of a B. & W., Heine or similar type of boiler and the grate surface, and at least 7′ between the rear of the grate and the tubes of a Stirling, Connelly or similar type boiler, where they enter the lower drum. When this stoker is used for burning lignite fuel, the design of the arch is again of utmost importance, because these coals contain from 25 to 40% moisture and it is necessary to provide a drying out process before they can be burned. There should be provided at least 10′ between the boiler tubes of a B. & W., Heine or similar type boiler and the grate, and at least 7′ when this stoker is applied to the Stirling, Connelly, or similar type of boiler between the rear of the grate and the tubes where they enter the bottom drums.

THE FLOW OF HEAT THROUGH FURNACE WALLS

After careful investigations and research work, by the Bureau of Mines, U. S. Geological Survey, bulletin number 8, gives the following conclusions regarding the heat flow through furnace walls.

In the case of the furnace wall, where the quantity of heat passing between any two planes which are parallel to the surfaces of the walls is the same, the temperature difference between any two planes indicates the resistance which the material or space between the two planes offers to the flow of heat. For example, if the temperature difference between

the faces of the firebrick wall is high, it may be said that the resistance to the heat flow of the firebrick wall is high; or, if the temperature difference between the two surfaces on each side of the air space is low, it may be inferred that the resistance to the heat passage across the air space is low. Thus it is possible to rely on the temperature difference as being a true indicator of high or low resistance to heat flow between any two planes which are parallel to the surface of the wall. With this knowledge the reader can turn to the charts and study the resistance of the firebrick, the air space, the asbestos layer, and the common brick, and the relative value of these materials as heat insulators in the construction of furnace walls.

Fig. *83* gives the temperature drops through the side wall as recorded by the set of couples placed at *b*, and through the roof as recorded by the set of couples placed at *c*. At the foot of the figure is shown diagrammatically the thickness of the side wall, and at the top of the figure is shown thickness of the roof; in each case the measurements of thickness are used as abscissae in the chart. The temperatures at the various points are platted as ordinates. The figure shows three temperature gradients or drops through the wall and through the roof, one at 11 a. m., April 12, when the test was started, one at 4 p. m. the same day, and one at 2 p. m. the next day. The first two gradients give the relation of the temperatures before the equilibrium is reached, and are interesting only when compared with one another to show how the temperatures change with respect to each other while the walls are being heated. The last gradient represents the equilibrium and is most of interest.

The striking feature concerning the side wall thermocouples, set *b*, is the large temperature drop through the firebrick wall, the very small drop through the air space, and, again, the large temperature drop through the common brick wall. These drops plainly indicate that the resistance to heat passage of the air space is very low compared with that of either brick wall, only about one-fourth as much. The last temperature gradient through the roof, as given by the set of thermocouples *c*, show a rather low temperature drop through the

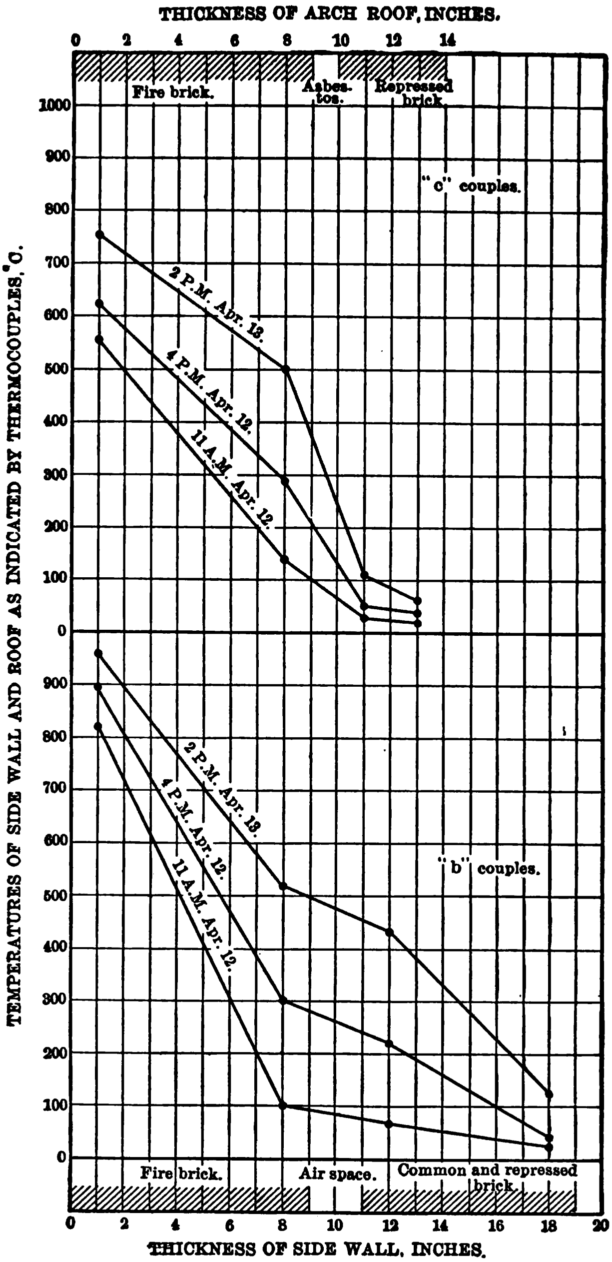


FIG. 83.—Temperature Drops through Furnace Walls.

firebrick, a high drop through the 1 inch layer of asbestos, and a rather small drop through the common brick. These temperature drops indicate that the resistance to heat flow of the 1 inch asbestos layer is higher than that of 7 inches of firebrick. By comparing the last gradient of couples *b* with that of couples *c*, it is easy to see that 1 inch of asbestos is much more effective as a heat insulator under the existing conditions than a 2 inch air space. Although the total thickness of the roof is 5 inches less than that of the side wall, a smaller quantity of heat per sq. ft. is lost through it than through the side wall.

The results of the investigation as outlined in this bulletin justify the following conclusions:

In furnace construction a solid wall is a better heat insulator than a wall of the same total thickness containing an air space. This statement is particulary true if the air space is close to the furnace side of the wall, and if the furnace is operated at high temperatures. If it is desirable in furnace construction to build the walls in two parts, so as to prevent cracks being formed by the expansion of the brickwork on the furnace side of the walls, it is preferable to fill the space between the two walls with some "solid" (not firm, but loose) insulating material. Any such easily obtainable materials as ash, crushed brick, or sand offer higher resistance to heat flow through the walls than an air space. Furthermore, any such loose material by its plasticity reduces air leakage, which is an important feature deserving consideration.

CHAPTER VII

STOKER EQUIPMENT OF MODERN STEAM POWER STATIONS

A study of the fuel burning equipment of the most modern plants will show that every consideration is being given to those details which provide for a balancing of the economic results that come from a careful selection of equipment, good supervision and correct operation. It will be found that elaborate means are being provided so that the boiler room organization can do things easily. It is no longer necessary for firemen to climb ladders and crawl over the boiler tops to change the position of dampers, although such methods are still common in many old plants. Mechanisms are being placed at the hands of the operators so that it is not necessary for them to go to inconvenient places in order to control operating conditions.

The most generally used fuel burning equipment in the modern stations is the "inclined multiple retort" underfeed and the "chain grate" stoker, designed for large boiler units, ranging from 1200 to 1500 H.P. up. A number of boilers containing 12,500 sq. ft. of heating surface have been used and are furnishing steam for 7000 to 8000 kw. in the prime mover. It is not at all improbable that this unit will be further developed to furnish steam for at least 10,000 kw., in the prime mover for continuous operation. These units are set singly with large alley ways between each setting, so that the boiler and fuel-burning equipment are accessible on all sides. The stokers are designed for a flexible operation of 50 to 300 per cent rating. Clinker grinders are used in a number of cases for discharging the ash and refuse automatically from underfeed stokers.

The following brief description of the fuel-burning equipment installed in a number of modern power stations covers

a wide range in the character of load and fuel used. Some of these plants are completely new stations, while others are extensions to old stations, and still others are old stations in which inadequate fuel-burning equipment has been replaced by more modern equipment.

EDISON ELECTRIC ILLUMINATING COMPANY.
Boston, Mass.

This company replaced old fuel-burning equipment under eight 512 horse power boilers with inclined underfeed stokers. One of these stokers was equipped with a clinker grinder, the idea being to try this out under regular operating conditions and with the fuel available, this being a part of a study for the new extension to the station. Although the stoker was of small size (five retorts), the clinker grinder operated satisfactorily and it was decided to use this design in connection with the equipment for the new extension consisting of four cross-drum boilers, 42 sections wide, 14 tubes high and 18 ft. long, rated at 1232 H.P., at 300 lbs. gauge pressure equipped with a superheater designed to give 150° superheat.

These stokers, as shown in Fig. *84*, are of the Westinghouse underfeed type, having 13 retorts installed under the back end of the boiler, under the mud drums, and equipped with rotary clinker grinders (Fig. *85*) for removing the ash and clinker continuously. The stoker drives (Fig. *86*) are divided with not over four retorts to a motor; also, the wind boxes and dampers are so arranged that they can be controlled on the same basis, this provision being made so as to give a complete control of coal and air across the entire furnace width.

The coal used is New River, of approximately the following analysis:

Fixed carbon	73.50
Volatile	20.75
Ash	5.75
Moisture	3.25
Sulphur	1.05
B.T.U.	14,700

The average per cent of combustible in the ash and refuse is not to exceed 15 per cent. The stoker equipment, when supplied with the above fuel, is designed to develop 300 per cent of normal rating of the boilers for periods of short duration.

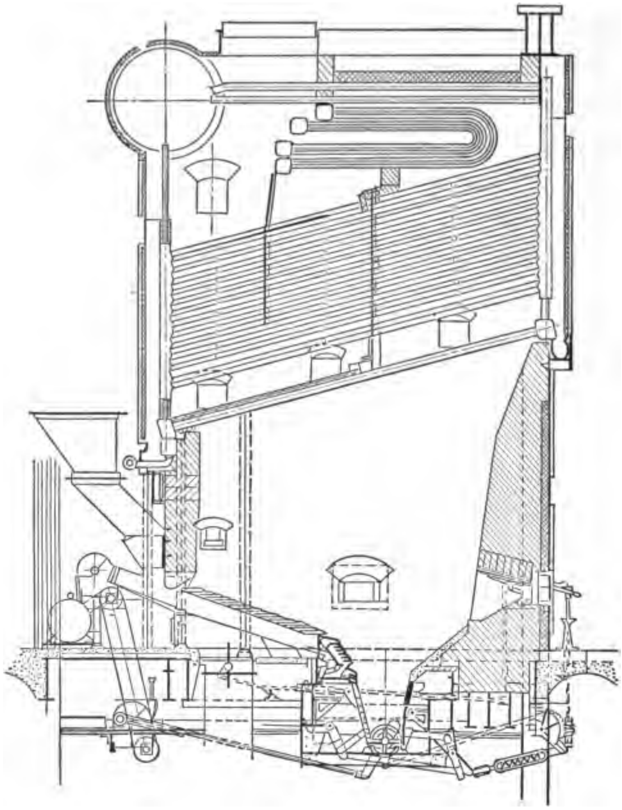


Fig. 84.—Boston Edison Stoker Setting, Showing Clinker Grinder and Furnace Control Mechanism Located at the Front of the Boiler.

Doors are placed in the bridge wall and all controlling mechanism placed at the end opposite the stoker (Fig, *84*) so that when the operator views the furnace fires through the bridge wall doors, he will have the controlling mechanism at hand.

UNITED ELECTRIC LIGHT AND POWER COMPANY, HELL GATE
New York City

The fuel burning equipment at this station consists of twelve 28-retort, type AA7 Taylor Stokers, each installed under

FIG. 85.—Interior View of Boston Edison Furnace, Showing Clinker Grinder and Front-wall Construction.

1890 horse power boilers. This type of Taylor Stoker has seventeen tuyeres and two feeding rams per retort. It is provided with double rotary clinker crushers of the same general design as those used on the Taylor Stokers at the Delray Plant of the Detroit Edison Company.

The combined boiler and furnace efficiencies of these units will range from 76% at 150% of rating to approximately 63% at 360% of rating, when burning Eastern Bituminous coal of approximately 13,000 B.T.U. per pound as fired.

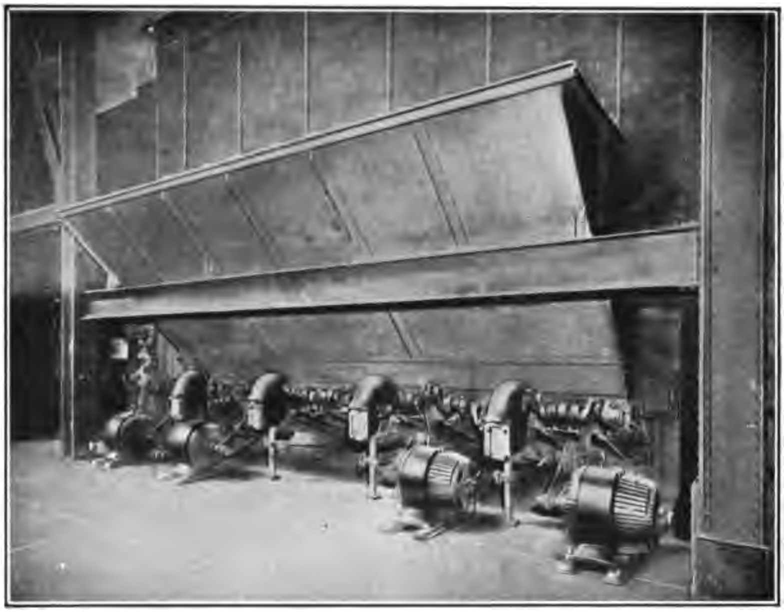


Fig. 86.—Front View of Boston Edison Stokers, Showing Motor Driving Equipment.

The ashes will be discharged directly into a flume from which they will be removed by water.

This stoker and boiler arrangement is shown in Fig. 87.

PUBLIC SERVICE ELECTRIC COMPANY,

Newark, N.J.

The "Essex" station of the above company, located on the Passaic River about two and one-half miles from Newark, N. J., was placed in operation in 1915. The boiler room equipment consists of B. & W. Cross Drum boilers of 1373 horse power each with an operating pressure of 225 pounds and superheat of

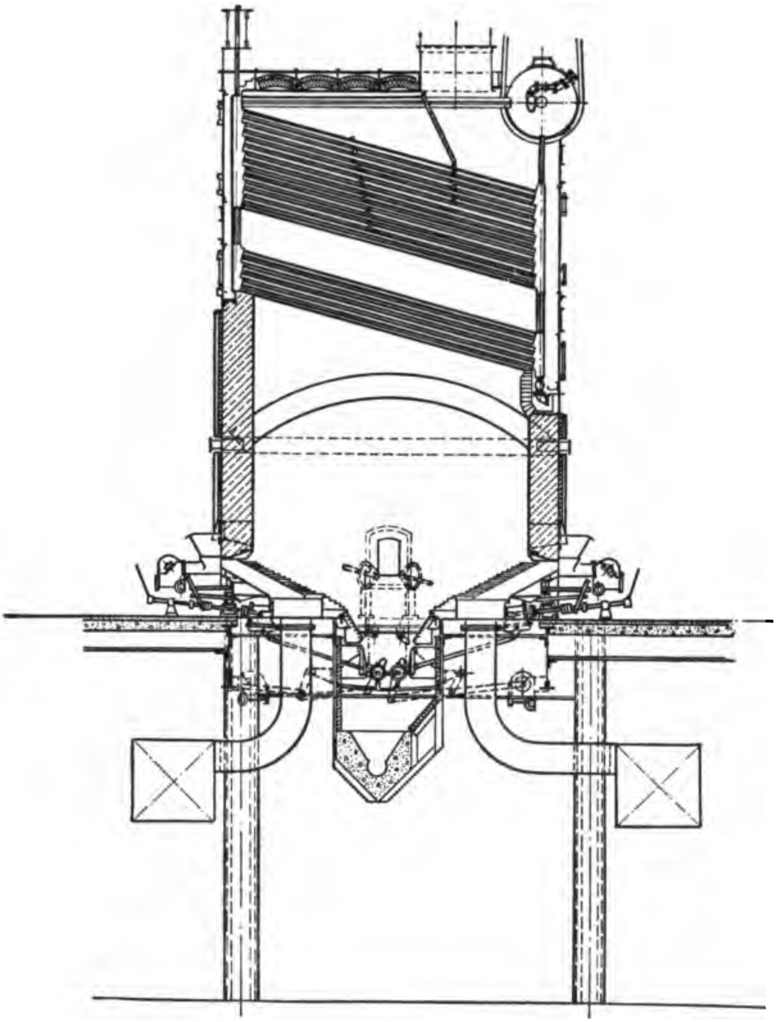


FIG. 87.—Setting of Stokers and Boilers of the Hell Gate Plant, United Electric Light & Power Company.

100° F. Each boiler is equipped with 16 retorts, Riley Underfeed stokers, in a Duplex setting (Fig. *88*). The stoker equipment was designed to burn up to 15,000 pounds per hour, when burning Pittsburgh coal of about 13,500 B.T.U. (as fired) and to develop about 500% and 600% of boiler rating for short periods.

Fig. 88.—Stoker Installation Public Service Electric, Showing Stoker Operating Board.

PHILADELPHIA ELECTRIC COMPANY,

Philadelphia, Pa.

Delaware Avenue Station

At this Station special type Stirling boilers of 1508 horse power each are equipped with fifteen retort type BA7 Taylor Stokers (Fig. *89*). These stokers have twenty-two tuyeres and three rams per retort. They are provided with double roll clinker crushers and are capable of operating the boilers up to 330% of rating, when burning Eastern coal of approximately 13,800 B.T.U. per pound as fired, and having the following proximate analysis:

Moisture	2.3
Volatile	22.5
Fixed Carbon	65.0
Ash	10.2
Sulphur	1.83

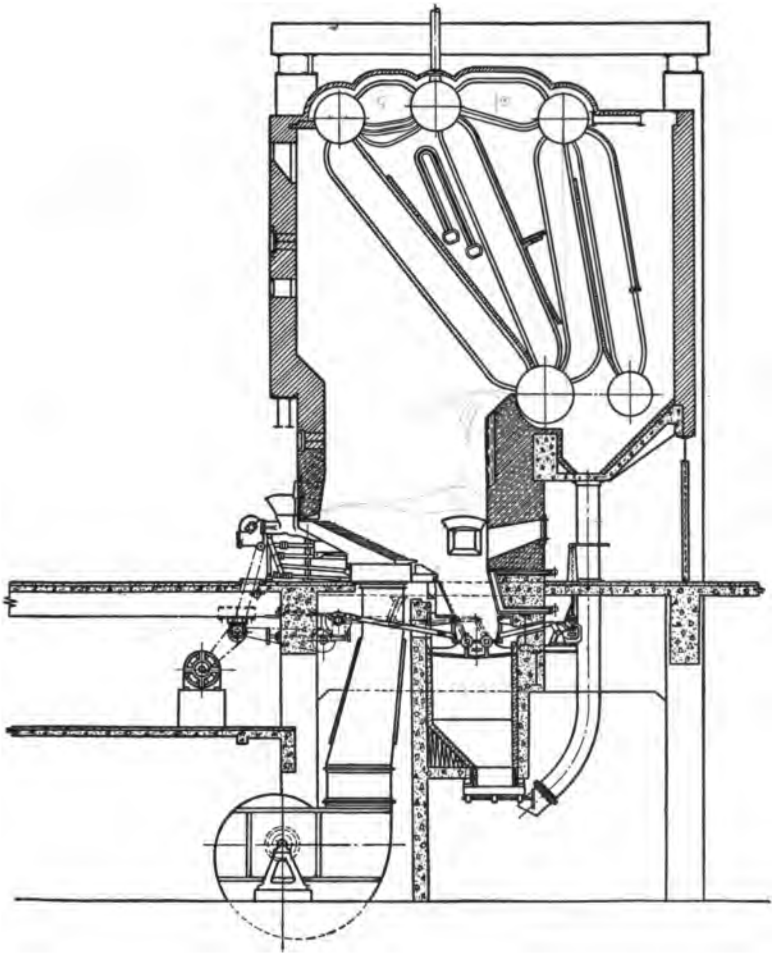


FIG. 89.—Setting of Stokers at Philadelphia Electric Delaware Avenue Station.

The efficiencies of the combined unit (boiler, furnace and economizer) will range from 82% at rating to 70% at 250% rating.

CONSOLIDATED GAS AND ELECTRIC CO., Baltimore, Md.

At the Westport Station of the Consolidated Gas & Electric Company, Baltimore, 11-retort 22-tuyere type Taylor Stokers, similar to Fig. *91*, are in service under 1074 horse power Water-tube boilers.

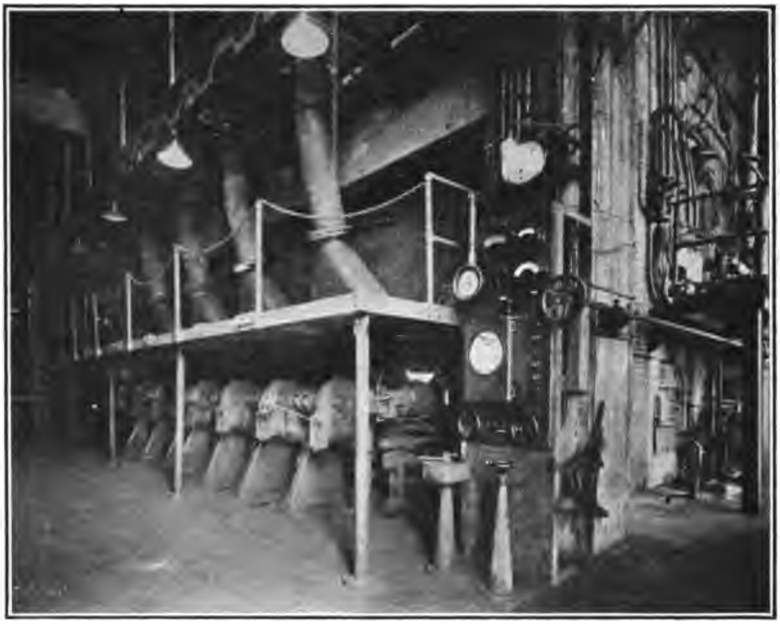


Fig. 90.—Interior View Delaware Avenue Station, Philadelphia Electric, Showing Stoker Operating Board.

These stokers are of the 22-tuyere type, and are equipped with power operated dump plates, which are designed to swing above the horizontal to clear the bridge wall of clinkers.

This installation is designed to burn Eastern coals of the following characteristics:

Moisture	2.00
Volatile	18.00
Fixed Carbon	62.00
Ash	16.00
Sulphur	2.00
B.T.U. per pound (as fired)	12,600

This installation will burn sufficient of the above coal to develop 350% of boiler rating.

The efficiency through the normal range will run from approximately 72% at 250% of rating to 77% at 150% of rating.

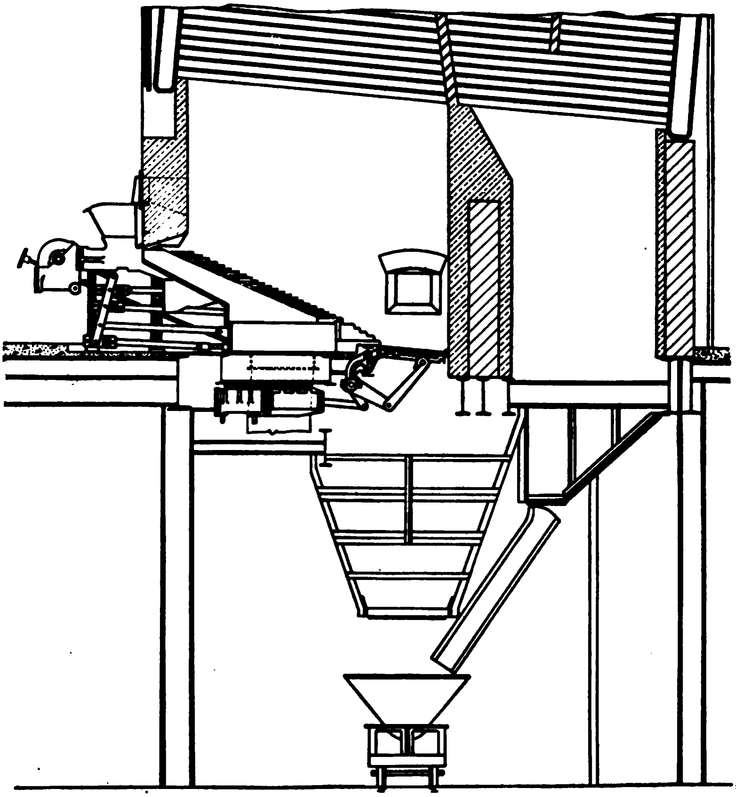


FIG. 91.—Setting of EdgeMoor Boilers and Taylor Stokers at Consolidated Gas & Electric Company.

BUFFALO GENERAL ELECTRIC COMPANY,
Buffalo, N. Y.

The Niagara River station of this company was built in 1916 with an ultimate total capacity of 200,000 K.W. The fuel burning equipment consists of ten 1140 horse power cross drum boilers of the B. & W. type. The stoker equipment was designed for burning Pittsburgh coals of the following analysis:

Moisture	3.00
Ash	10.00
Sulphur	2.00
B.T.U. (as fired)	13,500

To eliminate, as much as possible, the formation of clinkers, air boxes were designed for installation in the sidewalls. Each boiler is served by two 15-retorts, Standard Riley Underfeed stokers (Fig. *92*) arranged in a Duplex setting. The furnace width is 24 ft. and the depth about 17 ft. 6 inches. The total grate area under each boiler is 417.8 square feet. The stokers are set so that there is a height of 10 ft. 10 inches from the top of the grate to the front header and 6 ft. from the top of grate to rear header. When the boilers are operating at normal rating at 275 pounds working pressure and 275° superheat, the rate of coal feed by the plungers is 127 pounds per retort per hour. When feeding 700 pounds of coal per retort per hour the boilers will operate at about 500% of boiler rating. Estimating the average thickness of the fuel bed as two feet there would be in the furnace at all times about twenty-three tons of green coal and coal in process of combustion. The equipment is designed to operate between 500% and 600% of boiler rating for short periods.

CLEVELAND ELECTRIC ILLUMINATING COMPANY, Cleveland, Ohio

The Lake Shore station of the above company is a large central station furnishing electricity for the community in and around Cleveland. The boiler-room equipment consists of class M-25 685 horse power Stirling Boilers, equipped with 12 ft. wide by 15 ft. long Green Chain Grate stokers. These stokers are of the combination KLM type Green design for handling free burning coal. The boilers are set with what is known as a rear end setting. The central line of the mud drum being 15′ 8″ above the floor line (Fig. *93*). This gives an unusually large combustion space, there being 16 cubic feet furnace volume per square foot of grate surface.

The coal generally used at this station comes from South-

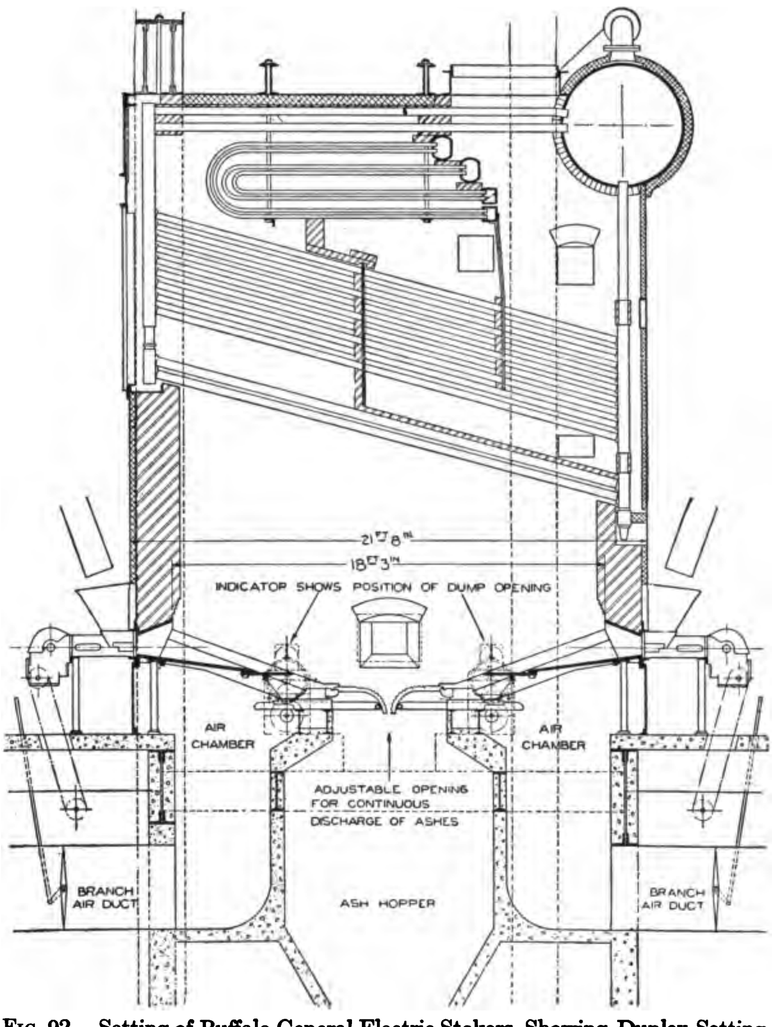


FIG. 92.—Setting of Buffalo General Electric Stokers, Showing Duplex Setting of Riley Stokers.

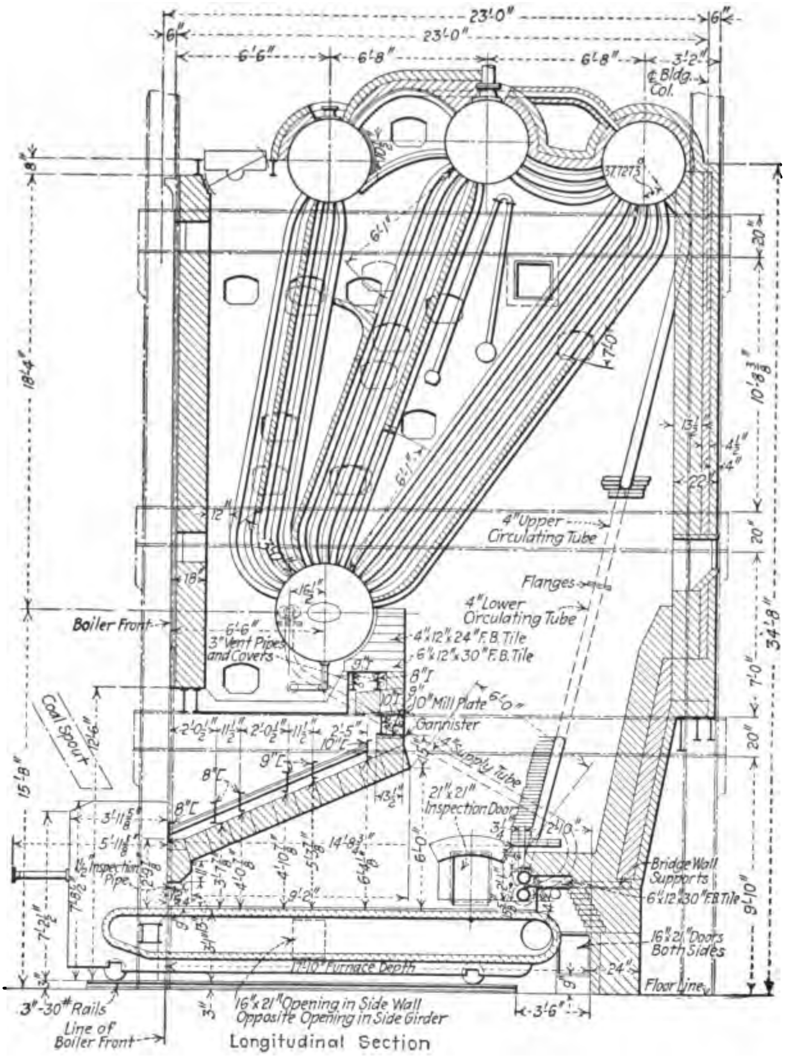


Fig. 93.—Setting of Green Chain Grate Stokers with Stirling Boilers, Cleveland Electric Illuminating Company.

eastern Ohio, which is free burning coal. The analysis running about as follows:

Moisture	2.90
Volatile Matter	31.4
Fixed Carbon	55.0
Ash	13.6
Sulphur	4.4
B.T.U. (dry)	12,350
B.T.U. (as fired)	11,992

The stoker equipment was designed for a range of operation from 100% to 300% of boiler rating. The average operating rating being about 175%.

The stoker equipment is designed to give from 70% to 75% combined boiler and stoker efficiency when operating at this rating.

DUQUESNE LIGHT COMPANY,
Pittsburgh, Pa.

The "Colfax Station" of the above company located at Springdale, Pa., on the Allegheny River was designed for an ultimate capacity of 300,000 K.W. The location of this station makes several sources of coal supply available. The stoker equipment consists of 17 retorts, Westinghouse Underfeed stokers applied to B. & W. Cross Drum boilers, each having heating surface of 20,706 square feet. The ratio of furnace volume to boiler rating is 3.45 cubic feet. The boilers are 18 tubes high by 15 tubes wide (Fig. *94*). The stoker equipment was designed for burning high volatile Pittsburgh coals of the following analysis:

Fixed Carbon	54.00
Volatile	34.00
Moisture	3.00
Ash	9.00
Sulphur	1.23
B.T.U. (as fired)	13,500

Double roll clinker grinders were installed, the same being cooled by a continuous water spray. To eliminate as much as

possible the formation of clinkers, air boxes were designed and installed in the side and bridge walls. The boiler and stoker efficiency of the plant under regular operating conditions were

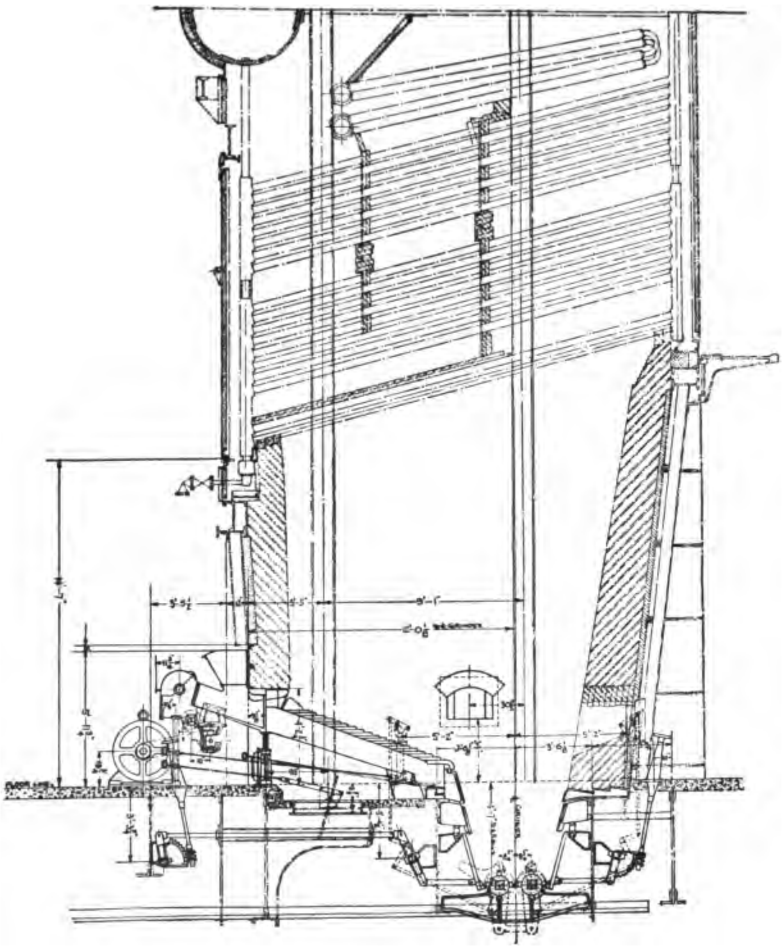


Fig. 94.—Setting of Westinghouse Stokers and B. & W. Boilers, Colfax Station—Duquesne Light Company.

designed for 78% at 100% of boiler rating and 65% at 300% of boiler rating. The entire stoker equipment was designed for 250% of boiler rating.

WEST PENN POWER COMPANY,
Pittsburgh, Pa.

The design of the new plant of the West Penn Power Company, on the Allegheny river above Pittsburgh, contemplated some decidedly novel features in the boiler and stoker equipment. The initial installation was designed for six boilers of

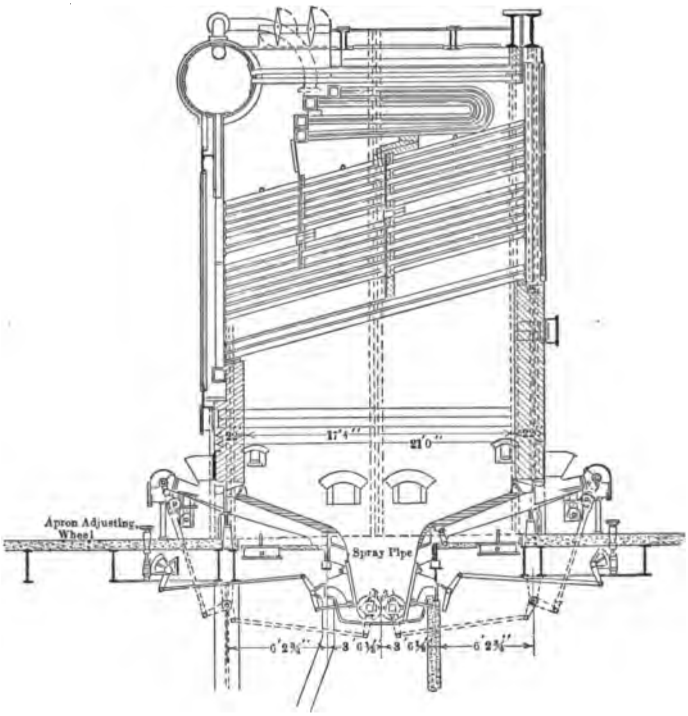


Fig. 95.—Stoker and Boiler Installation, West Penn Power Company.

the cross-drum vertical-header type, 42 sections wide, 16 tubes high, 20 ft. long, set with the front header 16 ft. above the floor, each boiler being rated at 1,529 H.P. and equipped with superheaters designed to give 200 degrees superheat. Westinghouse Underfeed stokers are installed at the front and rear ends of the boilers (Fig. *95*) 14 retorts under the mud drum, and 14 retorts under the front of the boiler. The operating conditions being a maximum of 300 pounds gauge pressure, 200 degrees superheat.

The boilers are set in two rows with aisles about 15 ft. between, thus giving plenty of room around each boiler for proper operating facilities. The stoker drives are so divided that there are 7 or 14 retorts driven by one prime mover, and the wind box dampers are arranged to control separately the air for units for three or four retorts. The stokers are equipped with clinker grinders for continuously removing the ash and clinker. Pittsburgh coals with approximately the following analyses, are used:

	Coal "A"	Coal "B"	Coal "C"
Fixed carbon	57.38	49.56	56.55
Volatile	34.81	32.84	32.80
Ash	7.81	13.26	10.10
Moisture	5.52	0.94	0.55
Sulphur	1.50	1.20	0.79
B.T.U. (as fired)	13,500	11,748	12,713

The boiler equipment is designed so that the flue gas temperatures will range from 500 degrees at 150 per cent rating to 700 degrees at 300 per cent rating, the combined efficiency ranging from 75 per cent at 150 per cent rating, to 65 per cent at 350 per cent rating. Each stoker, when burning fuel as mentioned above, is designed to develop 350 per cent of boiler rating continuous with the clinker grinder in operation, and 400 per cent of boiler rating for peaks of short duration. Under these operating conditions, the combustible in ash is not to exceed 14 per cent.

AMERICAN GAS & ELECTRIC CO.,
Windsor, W. Va.

The plant of this company, located in the coal fields of Pittsburgh, is one of the largest power plant developments. The present boiler-room equipment, either installed or provided for, consists of 14 boilers with underfeed stokers similar to the equipment mentioned for the Union Gas & Electric Co. The setting of the stokers is shown in Fig. *96*.

DETROIT EDISON COMPANY,
Detroit, Mich.

The first installation of double set underfeed stokers under large boilers was made at the Delray Plant of the Detroit

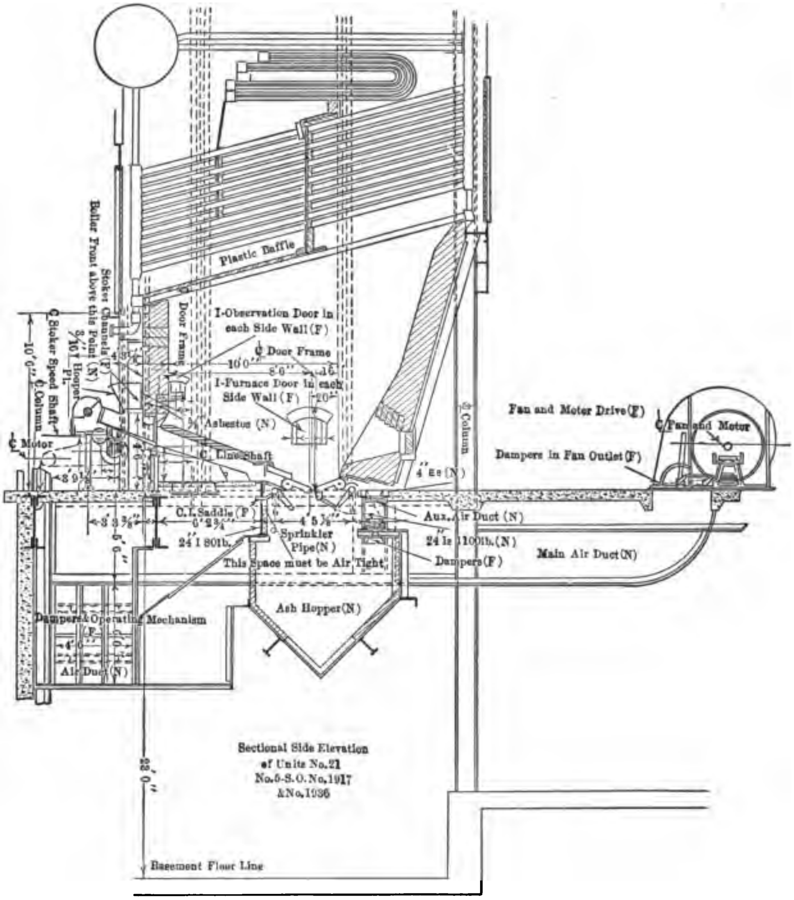


FIG. 96.—Stoker and Boiler Setting American Gas & Electric Co.

Edison Company. This consisted of two 13-retort Taylor Stokers, under each of the 2365 horse power water tube boilers, as shown in Fig. *97*. Roll clinker grinders were developed for these stokers and have been installed on the eight Taylor Stokered boilers of this type at Delray.

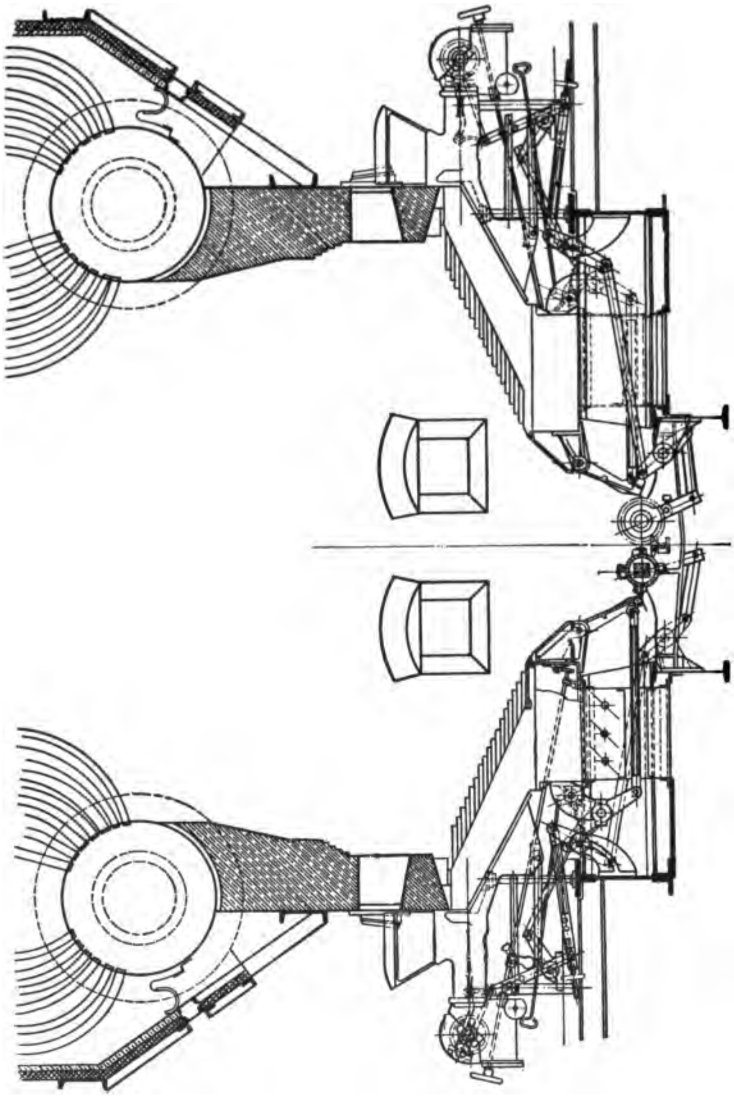


FIG. 97.—Sectional View of Taylor Stokers at the Delray Station of the Detroit Edison Company, Showing Clinker Grinder and Curved Grate Surface.

This equipment was duplicated for the ten units comprising the boiler and stoker equipment at the Connors Creek Station of this Company.

On test the efficiencies of these units have run from 80% at slightly above rating to approximately 77% at 200% of rating, when burning coal of approximately the following analysis:

Moisture	2.00
Volatile	33.00
Fixed Carbon	61.00
Ash	6.00
B. T. U. per pound (as fired)	14,000

The Congress Street, Willis Avenue and Farmer Street Stations have similar double set Taylor Stoker installations, but with a smaller number of retorts per unit. The Marysville Plant will have twelve-retorts, twenty-two tuyeres, double set Taylor Stokers under 2365 horse power boilers. This equipment will burn sufficient coal of 14,000 B.T.U. per pound as fired to develop 350% of boiler rating. The efficiencies will range from 80% at 150% of rating to 75% at 250% of rating.

UNION GAS & ELECTRIC CO.,
Cincinnati, Ohio.

In the new plant of this company there are installed cross-drum type boilers containing approximately 12,625 sq. ft. of water heating surface, with superheaters to produce 250 degrees superheat. Each boiler was made up of 42 sections each, 13 tubes high and 20 ft. long, the furnace width being 24 ft. inside the setting walls. Each boiler is equipped with economizers over the boiler and each boiler, with its economizer, is designed for evaporating 100,000 pounds of water per hour continuously from 100 degrees to steam at 250 pounds pressure, and superheated 250 degrees. The entire equipment is capable of evaporating 120,000 of water under the same conditions for short periods. The fuel-burning equipment is designed for burning West Virginia coal from the Kanawha district, containing approximately 12,500 B.T.U. per lb. as fired. The setting of these stokers is shown in Fig. *96*.

The stoker equipment is of the Westinghouse & Riley underfed type, each stoker containing 14 retorts placed under the rear of the boiler under the mud drum. The stokers consist of double dumping grates with arrangements for admitting air to them. The fuel-burning equipment is designed for combined efficiency ranging from 75 per cent, with a boiler capacity of 35,000 lbs. of water, to 65 per cent with a capacity of 100,000 lbs. of water. Each stoker is driven independently by direct-current motors connected by silent chain drives to the line shaft of the stokers. Instrument boards are installed to indicate to the operators the exact furnace conditions.

MERCHANTS HEAT & LIGHT CO.,
Indianapolis, Ind.

The above company replaced their former coal-burning equipment with Westinghouse underfeed stokers and, at the same time, added additional 800 horse power units to their plant, the entire work consisting as follows:

Twelve 500 H.P. Stirling boilers equipped with twelve 5-retort Westinghouse underfeed stokers.

Two 800 H.P. vertical boilers equipped with two 9-retort Westinghouse underfeed stokers.

Two 800 H.P. Badenhausen boilers equipped with two 8-retort Westinghouse underfeed stokers.

In the new settings, the lower drum of the boiler has been raised considerably so that doors could be placed in the bridge-wall.

The fuel-burning equipment was laid out to burn Indiana screenings of the following analysis, and when burning this fuel the operating performance ranges from 100% boiler rating to 300% boiler rating for short durations:

Fixed Carbon	43.89
Volatile	40.27
Moisture	15.23
Ash	15.84
Sulphur	3.99
B.T.U.	12,053

UNION ELECTRIC LIGHT & POWER CO.,
St. Louis, Mo.

The boiler plant of this company has been entirely revamped and a change made in the type of fuel-burning equipment formerly used. Careful study was made in regard to the installation of stokers, and it was finally decided to install underfeed stokers for use with good Illinois coal of the following analysis:

Fixed Carbon	48.9
Volatile	27.3
Ash	14.9
Moisture	9.0
B.T.U. (as fired)	11,112

The main problem at the start was that of designing the equipment to eliminate, as much as possible, trouble due to clinker formation on the side walls. After the equipment was in operation, and when using the coal that was originally contemplated, very little difficulty was encountered with clinkers.

Performance results are shown in Fig. *98*, when a grade of coal with the following analysis was used:

Fixed Carbon	41.0
Volatile	29.0
Moisture	9.0
Ash	21.7
B.T.U. (dry)	12,000

With this coal considerable more attention was required to keep the fires uniform and cleaned properly in order to decrease clinker trouble to a minimum.

COMMONWEALTH EDISON COMPANY,
Chicago, Ill.

The Northwest Station of the above company located on the Chicago River is one of the largest central stations using chain grate type of stokers.

The first section of this plant included 580 horse power B. & W. boilers operated at a pressure of 250 lbs. with superheat of 125°. The stoker equipment consisted of B. & W. chain grate stokers, twenty of which have 150 sq. ft. of grate surface each and twenty, 136 sq. ft. grate surface.

The last boilers installed were 1220 horse power cross drum B. & W. type, pressure 250 lbs. superheat 220°.

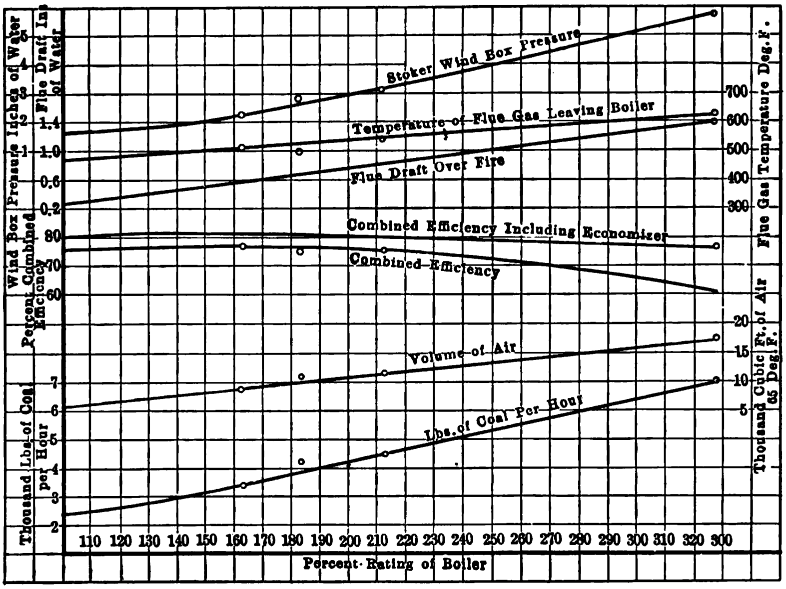


FIG. 98.—Performance of Underfeed Stoker when Burning Carterville Illinois Coal.

Illinois coal is used at this plant averaging about 10,000 B.T.U. as fired.

MINNEAPOLIS GENERAL ELECTRIC COMPANY, Minneapolis, Minn.

In re-designing the fuel-burning equipment of the plant of the Minneapolis General Electric Company (Fig. *99*), there were installed 12 Westinghouse underfeed stokers under twelve 600 H.P. boilers. A recent extension to this contemplated

the installation of five 14-retort underfeed stokers under five 1300 H.P. boilers. On account of the coal conditions prevailing at this plant, it was necessary to design equipment for two grades of coal of the following proximate analyses:

	Coal "A"	Coal "B"
Fixed carbon	56.48	43.49
Volatile	30.81	32.59
Ash	11.03	20.44
Moisture	7.00	10.00
Sulphur	1.70	3.48
B.T.U.	13,400 dry	11,200 dry

Fig. 99.—Underfeed Stoker Equipment of the Minneapolis General Electric Company.

Under the above conditions, the operating performance of fuel "A" ranged from 1800 to 3000 H.P. continuous and 4500 H.P. for short durations. With the poorer grade of coal, the Maximum capacity was reduced to 3600 H.P. for short duration.

DENVER GAS & ELECTRIC COMPANY
Denver, Colo.

Recent developments in the West have brought about the installation of underfeed stokers for burning coals found in Denver markets. The above company's new extensions included the installation of four 750 H.P. boilers and four nine retort Westinghouse stokers. The stoker application setting, worked out gives sufficient combustion space for any high volatile coals, including lignite, that are liable to be used at this plant. The fuel-burning equipment is designed for the following coals:

Fixed Carbon	39.00
Volatile	35.85
Moisture	19.70
Ash	5.37
Sulphur	0.42
B.T.U. (dry)	12,000

When using the above fuel, the operating performance ranges from 140% boiler rating to 200% boiler rating for short duration, with approximately 70% combined boiler and furnace efficiency.

CHAPTER VIII

APPLICATION OF STOKERS

DETERMINATION OF SIZE

While it is true that economy in fuel burning is largely the result of good operation it is necessary that the apparatus be properly proportioned to the work to be done. A poorly proportioned installation if skillfully operated may give as good or better results than one correctly proportioned and carelessly operated, but this does not relieve the engineer of responsibility for correct design and proportions.

Under best conditions, the range of efficient combustion rates is not great and under average operating conditions, this range is even smaller. As combustion rates are increased above the most efficient point, the amount of excess air will remain constant or may decrease slightly, indicating an increase in efficiency but this is more than offset by increased ash pit loss and the possibility of incomplete combustion. Below the point of best efficiency the ash pit loss should decrease but the loss due to excess air will increase more than enough to offset the decreased ash pit loss and the net efficiency decreases. The rate of this decrease depends upon the skill and care of the operators and in many plants is so rapid that the range of efficient combustion rates is very small. Fig. *100* shows the range for best conditions, the efficiency curve indicating what actually happens in many plants.

It is apparent that the engineer who selects the stoker and boiler must carefully consider the plant load conditions and select the correct proportions in order that the operators may be able to secure the best results.

If the plant has a substantially uniform load throughout the twenty-four hours, the best results so far as the boiler is

concerned will be secured at between 125% and 175% of rating. Variations within this range will depend upon local conditions such as cost of real estate, price and quality of fuel and necessity of providing future development.

For plants carrying a uniform load for from eight to twelve hours a day and banked the balance of the time, the fixed charges per unit of output will be greater and it is necessary to operate at higher ratings to secure the lowest operating cost. Under such conditions, the most economical rating will be between 150 and 200%, the exact figure being determined by local conditions.

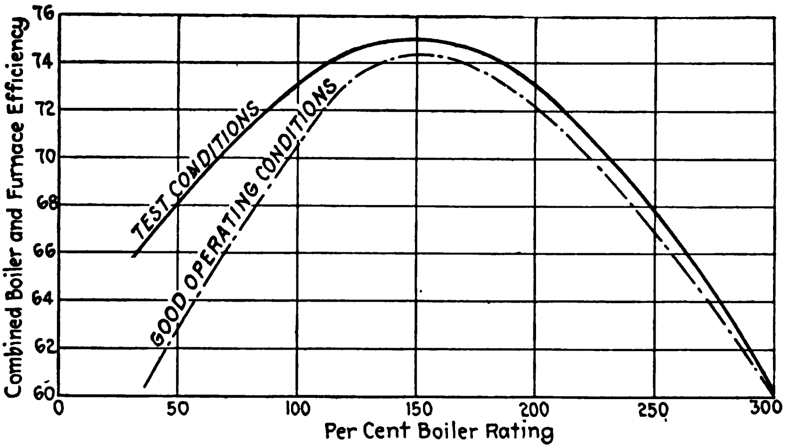


FIG. 100.—Typical Capacity-efficiency Curve.

The twenty-four hour variable load of the central station plant presents additional difficulties. The maximum capacity must be ample for the peak load and since the maximum peak occurs only a few times each year, the efficiency at which this peak can be carried is of little importance. The best results will be secured by proportioning the apparatus to carry the day load most economically and providing the necessary overload capacity to meet the peaks. If the day load can be carried at between 150% and 200% rating and the peaks by increasing to 250% or 300%, which represents the average condition, a satisfactory combination can be secured. If a greater peak load capacity is necessary, it is advisable to install stokers of

sufficient capacity to meet this demand rather than to increase the size and number of boilers, provided the peak load is not more than twice the day load. In general, it is not wise to design for a peak load on any unit of more than twice the average day load because at ratings below 50% of the maximum capacity, the efficiency will fall rapidly unless the best of operation can be depended upon.

The intermittent load of some industrial plants presents a particularly difficult problem. Sudden and unexpected steam demands must be met, in some cases without a large drop in steam pressure, and the equipment must be able to satisfy these demands regardless of economy. The selection of equipment must be such that the maximum demand can be supplied and the flexibility should enable the periods of low load to be carried economically, while the change from one condition to the other should be made quickly and automatically. Such a combination of requirements cannot always be met and the economy of operation will necessarily be lower than in a plant having a better load condition.

The selection of boiler equipment should never be made without at the same time considering the stokers, because the boiler proportions are determined largely by the size of stoker selected. A typical example will make this clear: Assume a plant being designed to carry a steady load of 3000 B.H.P. burning coal having 13,500 B.T.U. per lb. on underfeed stokers, and that a rating of about 150% has been decided upon as the most economical rating. This load could be carried on four 500 H.P. units, each developing 150% rating and the plant should contain five units, allowing one spare. The stokers should be of such size that three units could carry the load in case of a forced shut down of one unit. This requires 200% rating from each of the remaining units and it might be necessary to carry this rating for twenty-four hours. The stokers must therefore be of sufficient size to operate the boilers at 200% rating for twenty-four hours. Assuming 72% combined efficiency, the coal consumption per boiler per hour at 200% rating will be

$$\frac{34.5 \times 970.4}{13{,}500 \times .72} \times 1{,}000 = 3{,}440 \text{ lbs.}$$

at 150% rating and 75% efficiency, the coal burned per boiler per hour will be

$$\frac{34.5 \times 970.4}{13{,}500 \times .75} \times 750 = 2{,}483.$$

A stoker must be selected that will burn 3440 lbs. of coal per hour for twenty-four hours, but the most important requirement is high economy when burning 2483 lbs. per hour. For the given condition a combustion rate of 35 lbs. per square foot per hour should give the best results and the stoker size will be

$$\frac{2{,}483}{35} = 71. \text{ sq. ft.},$$

at 200% rating this stoker would have a combustion rate of

$$\frac{3{,}440}{71} = 48.5 \text{ lbs. per square foot per hour},$$

which is well within the reserve capacity of the type of stoker selected. These stokers are made in lengths of 9 ft. or more and it is therefore unnecessary to make the stoker more than $\frac{71}{9} = 7.9$ ft. wide.

In order to allow for the variations in dimensions employed by different manufacturers, it would be desirable to select a boiler having a furnace width of 9′ 0″ or the nearest standard width. Standard boiler designs for units of 500 H.P. can be secured in furnace widths up to 14′ 0″ and it is obvious that if such a design had been purchased without considering the stoker proportions, a serious mistake would have been made.

In general, it may be said that any given size or type of boiler will give better results if made as narrow as possible because the narrow unit gives a better distribution of the heating surface and will be a more efficient heat absorber. The stoker should be proportioned with this fact in mind and where several combinations of width and length are available, the narrow long one should be selected and the boiler proportioned accordingly.

In order that the best stoker size may be selected for any given condition, it is necessary that the best combustion rates

for the various grades of coal be known. Figs. *101*, *102* and *103* give these values for several typical fuels.

The minimum combustion rate recommended for continuous operation represents the lower limit for actual operation although good test results can be secured at lower rates. This requires careful operation and constant attention such as fires receive during tests or in regular operation in a few exceptionally well managed plants. Under average operating conditions, however, the efficiency will drop off rapidly at combustion rates below this minimum and unless it is absolutely

Combustion Rate per Sq. Ft. per Hour Dry Coal	EASTERN COAL F.C. 73 Vol. 17 Ash 6 S 1 Moisture 4 B.T.U. (Dry) 14300	PITTSBURGH COAL F.C. 57 Vol. 30 Ash 7 S 2 Moisture 4 B.T.U. (Dry) 13500	ILLINOIS COAL F.C. 48 Vol. 30 Ash 12 S 3 Moisture 10 B.T.U. (Dry) 12200	IOWA COAL F.C. 33 Vol. 27 Ash 25 S 4 Moisture 15 B.T.U. (Dry) 10400	LIGNITE F.C. 34 Vol. 33 Ash 10 S 1 Moisture 23 B.T.U. (Dry) 11500
Minimum for Continuous Operation	20 – 25	25 – 28	25 – 28	25 – 28	25 – 28
Recommended for Continuous Operation	30 – 38	32 – 40	30 – 38	28 – 35	30 – 35
Maximum for Continuous Operation	40 – 45	40 – 45	38 – 42	35 – 42	38 – 45
Recommended for 3 to 4 Hr. Peaks	50 – 60	50 – 60	45 – 50	42 – 45	45 – 50
Maximum for 3 to 4 Hr. Peaks	60 – 65	60 – 65	50 – 55	45 – 47	50 – 55
Maximum for One Hr. Peaks	70	70	60	50	60

FIG. 101.—Combustion Rates Recommended for Various Fuel Conditions for Forced Draft Underfeed Stokers.

necessary, provision should not be made for such operation. Some industrial plants having an intermittent load may be required to operate below this minimum but cannot reduce the number of units in service on account of the periods of heavy load which alternate with the low load periods, and such plants are at a definite disadvantage so far as economy is concerned.

The continuous combustion rates recommended for best results apply especially to plants having steady loads. It is usually necessary, however, to effect a compromise between this combustion rate and the maximum continuous rate. In the case cited above it is desired to carry a given load on four

boilers which in an emergency can be carried on three of the units. The most efficient combustion rate was thirty-five lbs. per sq. ft. of grate surface per hour and four units at this

Combustion Rate per Sq. Ft. per Hour Dry Coal	EASTERN COAL F.C. 73 Vol. 17 Ash 6 S 1 Moisture 4 B.T.U.(Dry) 14300	PITTSBURGH COAL F.C. 57 Vol. 30 Ash 7 S 2 Moisture 4 B.T.U.(Dry) 13500	ILLINOIS COAL F.C. 48 Vol. 30 Ash 12 S 3 Moisture 10 B.T.U.(Dry) 12200	IOWA COAL F.C. 33 Vol. 27 Ash 25 S 4 Moisture 15 B.T.U.(Dry) 10400	LIGNITE F.C. 34 Vol. 33 Ash 10 S 1 Moisture 23 B.T.U.(Dry) 11500
Minimum for Continuous Operation	15 - 18	18 - 20	18 - 20	18 - 20	18 - 20
Recommended for Continuous Operation	20 - 25	23 - 26	23 - 26	20 - 23	22 - 26
Maximum for Continuous Operation	25 - 28	30 - 35	30 - 32	25 - 27	26 - 32
Recommended for 3 to 4 Hr. Peaks	30 - 35	35 - 40	32 - 35	27 - 30	32 - 35
Maximum for 3 to 4 Hr. Peaks	35 - 40	40 - 42	35 - 40	30	35
Maximum for One Hr. Peaks	40	42	40	30	35

FIG. 102.—Combustion Rates Recommended for Various Fuel Conditions for Natural Draft, Overfeed Stokers.

Combustion Rate per Sq. Ft. per Hour Dry Coal	EASTERN COAL F.C. 73 Vol. 17 Ash 6 S 1 Moisture 4 B.T.U.(Dry) 14300	PITTSBURGH COAL F.C. 57 Vol. 30 Ash 7 S 2 Moisture 4 B.T.U.(Dry) 13500	ILLINOIS COAL F.C. 48 Vol. 30 Ash 12 S 3 Moisture 10 B.T.U.(Dry) 12200	IOWA COAL F.C. 33 Vol. 27 Ash 25 S 4 Moisture 15 B.T.U.(Dry) 10400	LIGNITE F.C. 34 Vol. 33 Ash 10 S 1 Moisture 23 B.T.U.(Dry) 11500
Minimum for Continuous Operation		20 - 22	20 - 22	20 - 22	20 - 22
Recommended for Continuous Operation		23 - 26	23 - 26	22 - 25	25 - 30
Maximum for Continuous Operation		30 - 33	32 - 35	25 - 30	35 - 40
Recommended for 3 to 4 Hr. Peaks		35 - 40	40 - 45	30 - 35	42 - 45
Maximum for 3 to 4 Hr. Peaks		40	45	35	45
Maximum for One Hr. Peaks		40	45	35	45

FIG. 103.—Combustion Rates Recommended for Various Fuel Conditions for Natural Draft, Chain Grates and Traveling Grate Stokers.

rate would carry the load, while with three in service, the combustion rate would increase to 48.5 lbs. If 45 lbs. was the maximum for continuous operation it would be necessary to increase the grate area to 76.5 sq. ft. thereby reducing the

combustion rate to 32.5 lbs. when four units were in service. This condition does not enter into the design of a large plant but is important in installations of three, four or five boilers.

In the selection of new apparatus, it is possible to proportion both boilers and stokers for best results but in the case of an old installation, this cannot always be done. Many boilers which are still in condition to give good service for years and therefore cannot be discarded, are not proportioned for stoker firing. The hand fired grate is limited to a length of about seven feet and it has been common practice in the past to make the boilers wide enough to permit of the installation of the desired grate area, based on a length of six or seven feet. These boilers are wider than would be selected today for stoker firing, but it is often necessary to equip them with stokers. In such cases it is important that the stoker be proportioned to suit the boiler furnace if best results are to be secured. The stoker should be made as wide as the furnace if possible and long enough to give the desired grate area. Some types of stokers are made in a variety of lengths and widths and are therefore more easily applied to these special cases than those designs which vary only in width.

The "grate area" of a stoker is a rather indefinite unit and depends upon the type of stoker and the methods of determination employed by different manufacturers but it makes little difference how this unit is determined because it does not affect the fuel burning capacity of a given stoker. If a manufacturer chooses to designate dump grates, coking plates, or dead plates as "grate area" thereby apparently increasing the size of the stoker, he must decrease the allowable combustion rate per sq. ft, while on the other hand, if these be eliminated from the calculations, the unit combustion rate will be correspondingly increased. It is desirable, however, for purposes of comparison that the same standard of measurement be applied to stokers of the same type in order that their comparative fuel burning capacities can be compared.

Overfeed stokers of the front feed type usually figure the area to be the product of the stoker width multiplied by the length measured along the line of fuel travel from the point where the fuel enters the furnace to the bridgewall. In some

cases, the dump grates are not included and in others they are given partial values. It is, therefore, desirable with stokers of this type to determine exactly how the grate area has been determined, especially when a comparison is to be made with some other type of stoker.

Side feed stokers are calculated on the basis of the distance from the inside of front wall to face of bridgewall, multiplied by the length of actual grate area measured along the

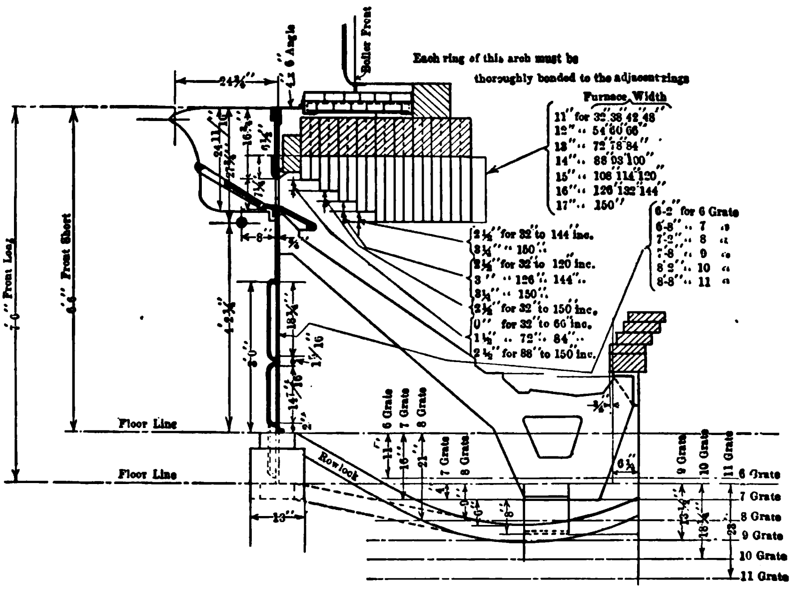


FIG. 104.—Dimensions of Westinghouse Roney Stoker.

grates. For convenience, in making calculations, the projected area can be multiplied by 1.4.

Multiple retort underfeed stokers have generally employed the retort as a unit but this is not a satisfactory unit of grate area because no two manufacturers have adopted the same retort dimensions and the situation is further complicated because the same manufacturer has more than one retort size. It is now generally accepted that the area in square feet should be specified and this is determined by multiplying the actual width by the horizontal distance from the inside of front wall to the face of the bridgewall. This includes dump grates or

other ash disposal devices but does not take into account the angle of the retorts.

Center feed underfeed stokers are figured on the basis of projected area enclosed by the four furnace walls.

Traveling grates are based on projected area enclosed by the side walls, feed gate, and water box. Forced draft stokers of this type do not employ the water box and the length should be measured from the inside of the feed regulating gate to the rear of the last wind compartment.

In the determination of correct stoker size for a given set of conditions, the following procedure will be found convenient—

Assume the following conditions:

Boiler size, 500 H.P.
Continuous rating desired........... 150%
Maximum rating for four hours...... 200%
Maximum rating for one hour......... 275%

Coal—Volatile..................... 32%
Fixed Carbon................ 54%
Moisture.................... 5%
Ash......................... 9%
Sulphur..................... 1%
B.T.U. dry..................13,500

Efficiency at................. 150% 75%
Efficiency at................. 200% 72%
Efficiency at................. 275% 65%

The calculations can be arranged as follows:

Per Cent Rating	Horse power Developed	Efficiency	Coal per Horse power	Total Coal per Hour
150	750	75	3.31	2483
200	1000	72	3.44	3440
275	1375	65	3.82	5253

For convenience in determing the pounds of coal required per boiler H.P., a diagram such as Fig. *105* may be used in

the following manner: locate the intersection of the vertical line of B.T.U. in the coal with the diagonal line representing the combined efficiency then project horizontally from this point to the heavy curved line. From this second intersection, project vertically to the scale representing pounds of coal per boiler H.P. The same diagram may be used to determine the equivalent evaporation per pound of coal by locating the intersection of the vertical line of B.T.U. in the coal with the

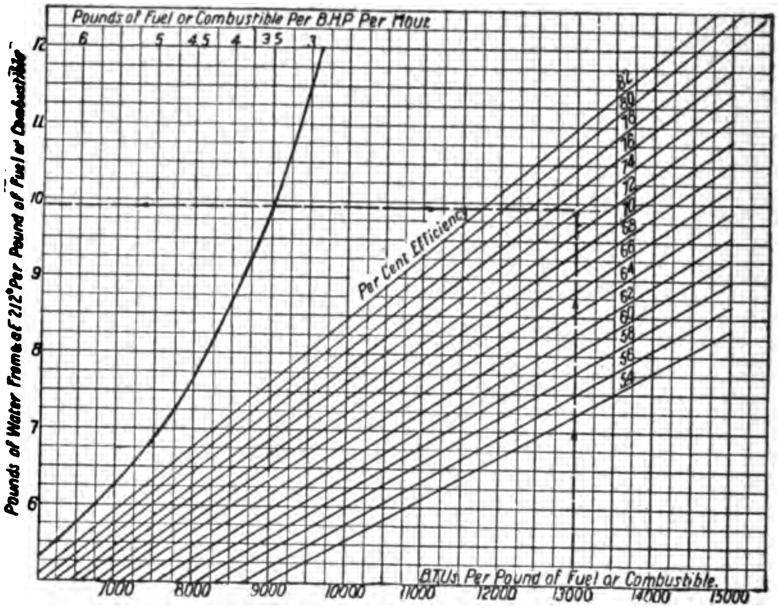


Fig. 105.—Efficiency Chart, Giving Pounds of Water from and at 212° F. per Pound of Fuel of Specified Heat Values.

diagonal line of efficiency and projecting horizontally from this intersection to the scale representing equivalent evaporation.

The stoker selected must be able to burn coal at the rate of 5253 lbs. per hour for a period of one hour and should be operating close to its most efficient combustion rate when burning 2483 lbs. per hour and the ability of a stoker to meet this condition must be considered in selecting the type best suited. All stokers under consideration must first be proportioned to meet the maximum demand and of the stokers thus propor-

tioned some will operate more efficiently than others at the average rating. This often has a greater influence on the type selected than any other factor. When the type has been selected, it may be found that the standard size built by one manufacturer meets the conditions best, and this fact must be considered in comparing details of stokers of the type which has been selected.

When the weight of coal to be burned has been determined, it is then necessary to select the best rate of combustion for the stoker under consideration. Figs. *101*, *102* and *103* give

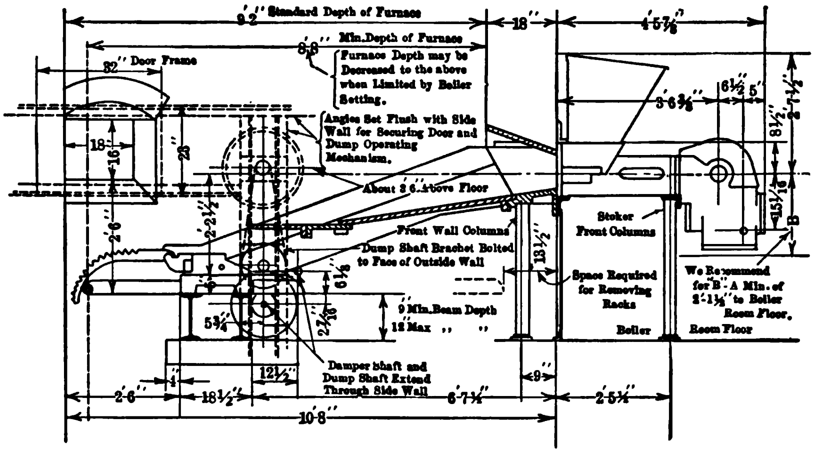


FIG. 106.—Dimensions of Riley Underfeed Stoker.

the combustion rates recommended for the different types of stokers and grades of fuel. Under test conditions, lower rates than those given can be maintained and higher rates than the maximum values can easily be secured. The same can be said of many well operated plants but these figures will apply to average conditions.

With the above information at hand, the grate area required for a given condition is readily determined. The next step is to choose the standard size of the stoker selected which most nearly meets the requirements and it is therefore necessary to know the units in which stokers are built.

SIZES AND DIMENSIONS OF THE MURPHY FURNACE

Furnace Number	Approx. Boiler H.P.	Grate Surface Projected	Grate Surface Effective	Width Furnace	Depth Furnace
1	40	9	11.91	3′	3′
2	50	12	15.88	3′	4′
3	65	14	18.66	3′ 6″	4′
4	72	16	23.31	4′	4′
5	80	18	26.37	4′ 6″	4′
6	90	20	28.69	4′	5′
7	90	20	29.44	5′	4′
8	100	22½	32.46	4′ 6″	5′
9	125	25	36.23	5′	5′
10	135	27	38.55	4′ 6″	6′
11	135	27½	40.00	5′ 6″	5′
12	150	30	43.03	5′	6′
13	150	30	43.78	6′	5′
14	170	33	47.50	5′ 6″	6′
15	190	35	49.82	5′	7′
16	200	36	51.99	6′	6′
17	215	38½	55.00	5′ 6″	7′
18	220	39	56.46	6′ 6″	6′
19	230	40	58.12	8′	5′
20	250	42	60.06	7′	6′
21	250	42	60.20	6′	7′
22	275	45½	65.37	6′ 6″	7′
23	290	48	68.41	6′	8′
24	290	48	69.02	8′	6′
25	300	49	69.55	7′	7′
26	320	52	74.29	6′ 6″	8′
27	325	52½	74.73	7′ 6″	7′
28	350	56	79.03	7′	8′
29	350	56	79.92	8′	7′
30	375	60	84.92	7′ 6″	8′
31	400	63	90.28	9′	7′
32	400	64	90.81	8′	8′
33	450	72	102.60	9′	8′
34	500	80	114.38	10′	8′
35	550	88	126.16	11′	8′
36	600	96	137.94	12′	8′

Overfeed stokers of the Murphy and Detroit type are made in width of from 3 ft. to 8 ft. varying by 6 in. and in depth from 3 ft. to 8 ft. varying by 12 in. When the furnace width exceeds 12 ft. two stokers are installed under one boiler.

Underfeed stokers of the multiple retort type vary the number of retorts which are made in two or more sizes. Any desired number of retorts can be combined into one stoker.

STANDARD SIZES—MULTIPLE RETORT STOKERS

Type	Length	Retort Width	Grate Area, Square Feet
RILEY			
Short	8′ 8″	19″	Number of retorts × 13.72
Standard	9′ 2″	19″	Number of retorts × 14.51
Ex. long (short)	10′ 8¾″	19″	Number of retorts × 16.93
Ex. long	11′ 2¾″	19″	Number of retorts × 17.78
TAYLOR			
Standard, 17 tuyere	9′ 0″	20¾″	Number of retorts × 15.56 + 2.62
Long, 22 tuyere	10′ 10″	20¾″	Number of retorts × 18.73 + 3.16
17 tuyere (with grinder)	9′ 6½″	20¾″	Number of retorts × 16.50 + 2.78
22 tuyere (with grinder)	11′ 4½″	20¾″	Number of retorts × 19.67 + 4.78
WESTINGHOUSE			
14 tuyere (double dump)	8′ 1¼″	21″	Number of retorts × 14.18 + 0.8
17 tuyere (single dump)	9′ ¾″	21″	Number of retorts × 15.86 + 0.95
17 tuyere (double dump)	10′ ¾″	21″	Number of retorts × 17.61 + 1.05
21 tuyere (double dump)	11′ 7¼″	21″	Number of retorts × 20.3 + 1.21

Center retort underfeed stokers are made in single units varying in width from 5 ft. to 14 ft. varying by 6 inches and in length from four feet to ten feet varying by one foot. Where the furnace width exceeds fourteen feet, two stokers are installed without a center wall between the units.

Traveling grates are made in width from four feet to fifteen feet, varying by six inches and in length from eight

feet to seventeen feet, varying by one foot. Where the furnace width exceeds fifteen feet, two stokers are installed with a center wall between the units.

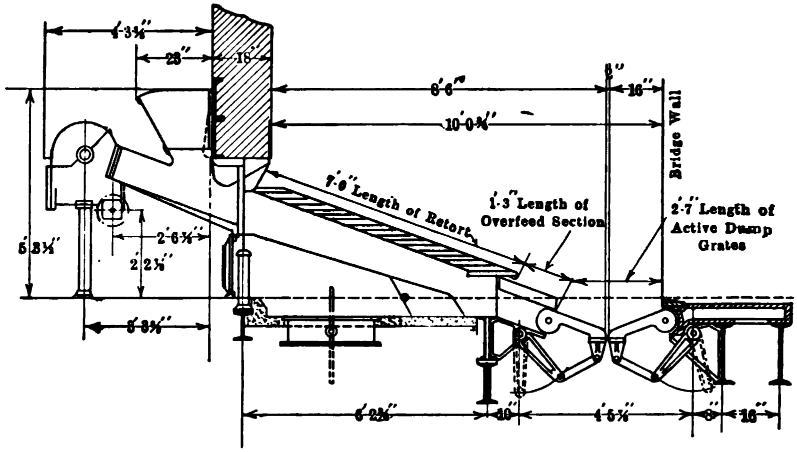


FIG. 107.—Dimensions of Westinghouse Underfeed Stoker.

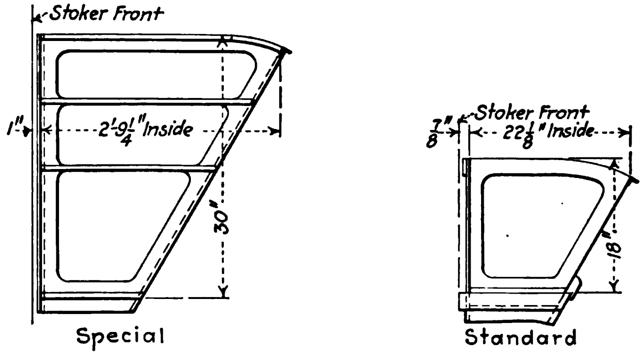


FIG. 108.—Dimensions of Standard Coal Hoppers.

CAPACITY OF COAL HOPPERS BASED ON COAL AT 50 POUNDS PER CUBIC FOOT

No. Retorts	Width (Inside)	Standard Hopper	Special Hopper
		Capacity, Pounds	Capacity Pounds,
2	2′ 6″	281	735
3	4′ 3″	478	1250
4	6′ 0″	675	1765
5	7′ 9″	872	2280
6	9′ 6″	1069	2795
7	11′ 3″	1266	3310
8	13′ 0″	1463	3825
9	14′ 9″	1660	4340
10	16′ 6″	1857	4855
11	18′ 3″	2054	5370
12	20′ 0″	2251	5885
13	21′ 9″	2448	6400
14	23′ 6″	2645	6915
15	25′ 3″	2842	7430

CHAPTER IX

INSTALLATION OF STOKERS—SPECIFICATIONS—CONTRACTS—GUARANTEES—BOILER ROOM LOG

There has been some improvements in recent years in the matter of boiler and stoker combinations. Boilers have been raised, stokers have been set differently; more attention has been given to the breeching design and higher stacks are being used. Still there has never been anything like the thought on this subject that there should be and the standardization of the practice that is necessary.

There is no reason for doing exactly the same things that were done years ago, still installations are going on nowdays the same as they did fifteen years ago. It is also not necessary to present exactly the same standard. When changes are made, however, there is need of an analysis of the installation and the information translated into some definite grasp of the subject, into some real data that can be distributed with confidence.

Whenever a stoker is installed in combination with a boiler, there are many things that must be considered and decided jointly by the purchaser, the boiler and stoker manufacturer. A definite conclusion must be reached on the following:

1. Height of the boiler header above the floor line—or height of boiler setting.
2. Setting of the stoker.
3. Combustion space necessary for the coal to be used.
4. Design and location of the breeching.
5. Size and location of the stack.
6. Area of gas passages through the boiler.
7. Area of damper openings.
8. Facilities for cleaning soot off boiler baffles and boiler tubes.
9. Grade of firebrick to be used in the furnace construction.

10. Size of walls of boiler and furnace setting.
11. Size and grade of firebrick for arches.
12. Method used to control dampers.
13. Construction of ash pit and facilities for disposing of the ash.
14. Method of conveying coal to the stoker hoppers.
15. Locations of fans, etc.
16. Design and location of air ducts.

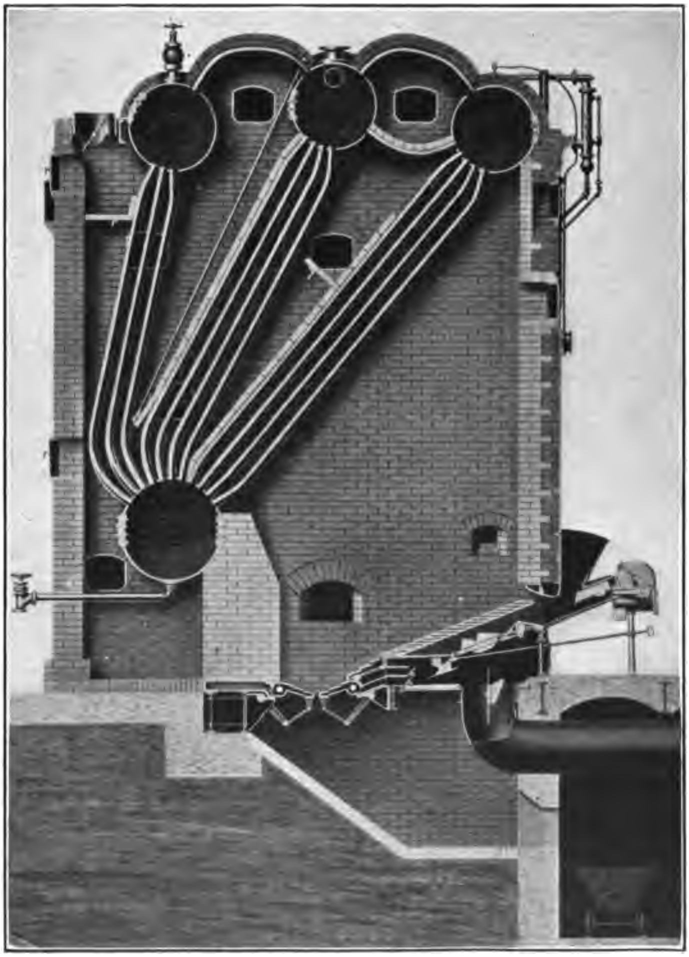


FIG. 109.—Typical Underfeed Stoker Application.

If the purchaser failed to install the height of stack that was necessary, he would be the one that was responsible for the failure. If the stoker manufacturer did not take a firm stand and hold out for the correct setting of the stoker, he would be responsible for the failure. If the boiler manufacturer failed to provide the correct areas for the passage of the furnace gases and arrange to set the boiler at a height required for the particular stoker selected, he would be responsible for the failure.

Of course, some of the items mentioned are more important than others. Slighting some of them would not ruin an installation entirely, while slighting others would make an installation absolutely a failure.

The question arises as to how those interested are to know to what degree installations will be successful. One can hardly plan an installation for the future unless he has some conception of past installations. One must be capable of recognizing the strong points of installations and ascertaining the weak ones. Great care must be taken to see that the weak ones are not unduly attributed to other causes than the real ones. Names sometimes mislead. Very often when discussing a satisfactory installation the first question asked is—What is the name of the boiler and stoker? In most cases this has very little to do with the results obtained. It is true that some stokers adapt themselves more easily than others to particular boilers; and it may be true that some boilers are more easily set than others, but one cannot come to any definite conclusion as to the cause for a satisfactory or unsatisfactory boiler and stoker combination unless he knows, and has determined by careful analysis, the cause.

It is not intended that one should not be exact and resourceful in the handling of various materials that go to make up a good boiler and stoker combination. If it is not necessary to raise boilers, use higher stacks, etc., the reason why these things are not necessary should be known. It is right, however, to assert what we actually know in the planning of new work.

Installations are always being made that do not follow the principles that are commonly known to be right. One fre-

quently hears that boilers cannot be set higher because the contract for the masonry work has been included with the boilers; or, that the contract has already been let and the purchaser will not pay the extra cost of setting the boilers the way they should be set with the particular stoker selected. Again, we frequently hear that the boilers cannot be set right because the architect has previously provided so much room for the boiler and stoker and they must go within the limit provided, whether a good combination or a bad one is obtained. Plans continue to be made in the wrong way and unsatisfactory installations result.

There is another phase of this problem that seems to interfere with obtaining good installations; that is, the cost of the installation. Of course, boilers being raised, stokers extended, higher stacks, etc., cost more money. The boiler and stoker manufacturers must take a sufficiently firm stand for the combinations that are known to be right and be sure that money is expended to make them right.

A case is recalled where the contract had been closed for boilers, stokers and the brickwork. The boilers were to be set a certain height and the contract was let with the masonry figure on this type of setting. The setting did not agree with what the stoker manufacture thought was right and he took a firm stand that the boiler should be raised. If the purchaser, the boiler and stoker manufacturers, in this case, had coöperated and definitely decided the points mentioned in the forepart of this Chapter enough money would have been expended to obtain the right kind of a combination.

It does not seem possible that the plans and methods adopted in one section of the United States could be followed with the same degree of exactness and success in another, quite remote, or any other place where coal and installation conditions are different. It would seem that each community where coal conditions are about the same should obtain their own data. The time has not come when a combination can be standardized in the west and be adapted to the conditions in the east, or vice versa, with success.

Conditions are daily encountered that are prejudical to good furnace performance. One plant that was investigated

will present a typical example of conditions to be found in many other plants. This plant operated twenty-four hours a day and had six water tube boilers installed, each of 250 horse power rated capacity. The boilers were served by one stack, 9 ft. in diameter by 150 ft. high. There was one long breeching connecting all the boilers. A short breeching connected the main breeching to the stack. The complaints were excessive labor and great difficulty in maintaining the steam pressure necessary to operate the plant. Considerable money was spent in sending engineers to the plant with instructions to assist in every possible way to better the operating conditions. It was immediately found that the draft available in each furnace was low and insufficient to burn the coal required. Arrangements were made to carefully analyze this draft condition and find the cause of the troubles. There was an available draft in the stack of about .90″, and in the short breeching, about .83″. At points in the main breechings, however, only a few feet away, the draft dropped to about .53″, indicating a loss of .3″ draft in the right angle turn to the main breeching. The investigating engineers reported the boilers dirty and on several occasions 3/16″ scale was removed from the tubes. It was also found that the boilers were only cleaned every six months and the soot blown from the tubes every week. There was a heater installed and owing to the piping construction it could only be cleaned once a year. An inspection of the blow-off valves of the boiler proved that they all leaked.

In this particular case, the purchaser was at fault in not operating the plant properly and maintaining the equipment in good condition. Whoever put the breeching in was responsible for its faulty design. The stoker manufacturer was at fault if he knew of the breeching design; he should have cautioned the purchaser regarding draft losses.

A peculiar situation arose in analyzing the conditions of this plant. The owner's operating engineer reported the boiler free from scale. The investigating engineer reported the boilers badly scaled. It was finally necessary to have the manager of the company personally inspect the boiler on which reports were being made. In his personal investigations small

spots of scale in the tubes were noted which the turbine had skipped. The operating engineer claimed that this was a trivial matter. The manager, however, insisted on having all of the scale removed. This was done and five wheel barrow loads of scale were removed from this one boiler—this scale being removed after the owner's operating engineer had reported the boiler clean.

After all the causes of the troubles at this plant were determined, it was arranged to correct them. The results obtained were astonishing after everything was fixed up and a better practice established in cleaning boilers. The important part of the analysis is this: The matter had to be sifted down and the causes of the troubles determined without question and presented to the management of the company. This cost money—who was to pay for it? If someone had not found the troubles and expended the money necessary to find them, the result would have been dissatisfaction with the entire equipment; the stoker would have been thrown out; boilers condemned; probably money unnecessarily expended on a new stack and the owner convinced that some one made a mistake in the original purchase of the equipment.

In this kind of work there is always a question of whether or not the trouble is due to the stoker and boiler equipment; the operating conditions, or the design of the breeching and stack. It is necessary, therefore, to make a careful analysis and obtain sufficient engineering facts that will properly place the reponsibility.

There are many things that effect a boiler and stoker combination and unfortunately the purchaser or user cannot appreciate how anything wrong with a part of the equipment can effect another part.

A few years ago the stoker manufacturer had very little control over the things that determined whether a stoker installation would be a success. As an example of this, a combination was installed, where the stoker manufacturer inquired as to the height of stack selected for the 500 H.P. boiler to obtain the 3/8″ draft specified for the furnace. He was told by the architect that the stack would be 100 ft. above the grates. The stoker manufacturer claimed that 100 ft. was

not enough and insisted on 150 ft. The architect was greatly astonished that such a height for this one boiler was necessary —he finally agreed, however, to make it 125 ft. The stoker manufacturer still insisted that a 125 ft. stack was not sufficient and nothing less than 150 ft. would do. Everything possible was done to convince the architect that this size stack was needed. It was finally decided, however, to build the 125 ft. stack, the purchaser approving the architect's opinion. The stack was built and sufficient draft was not obtained for the amount of coal it was necessary to burn—consequently the installation was a failure.

One stoker manufacturer cannot alone take a firm stand and hold out for a better practice in installations, neither can one boiler manufacturer, but there must be coöperation among all, in order to obtain the type of installation that is required.

Better practice could be obtained if the purchaser gave more thought to the whole combination of boilers, stokers, breechings and stacks.

The purchase of a stoker requires more thought than it is generally given. If a boiler and stoker combination is to be purchased to burn bituminous coal, the type of boiler and stoker should be determined first. It will not be attempted here to outline the things that must be considered in deciding this matter. There are all kinds of combinations that can be inspected. Time can be used to a good advantage by finding the good and bad points of local installations and thereby be assured that contemplated combinations will not duplicate faulty ones.

After the boiler and stoker has been selected, it is not yet time to finally decide whether or not these particular types should be purchased—it is not the time to sign the contracts. The purchaser should arrange a conference between the manufacturer of the boiler selected, and the manufacturer of the stoker selected. The whole combination and the things mentioned in the forepart of this chapter should be discussed in detail and a decision made on each matter, final decision to be based on good engineering judgement and experience. The purchaser should not obtain an opinion from the boiler manufacturer as to how the boiler should set, unless he gives the

stoker manufacturer an opportunity to present his opinions. If all points are settled on a good engineering basis, there will be no question but what the best combination known will be obtained and the customer can well afford to expend the money necessary for it. This practice of buying stokers and boilers has proved its effectiveness.

Many boilers and stokers are purchased by this method. One case is recalled where the purchaser decided on the boiler and stoker that he had in mind purchasing; he then called the boiler manufacturer, the stoker manufacturer and his consulting engineer who was designing the breeching, stacks, etc., in conference with him. He made the statement that he wanted the best combination of this type of boiler and stoker that he could get and wanted all conditions right for its proper operation. At this meeting the size of the stack was decided on, the setting of the stoker in combination with the boiler was arranged, the grade of firebrick that was to be used in the arches was selected; in fact, all matters, even to the minutest detail pertaining to this combination, was discussed and decided upon. After it was thoroughly understood between those present that in their opinion no changes could be made from those decided that would better the installation, the purchaser signed the contracts.

It is a fact that this installation is very satisfactory in every way. The purchaser of the equipment knew of other combinations of this same type of boiler and stoker that were failures. He also knew and was capable of determining the weak points of those installations and he made sure that the conditions were going to be right for the equipment he was purchasing.

The purchaser must expend the money necessary to obtain the best combination known; he must operate the equipment properly and keep it in good condition. The stoker manufacturer must take a firm stand for the proper setting of the stoker; he must hold out for the draft that is required to burn the coal and he must insist on the proper operation of the stokers. The boiler manufacturer must provide ample damper areas and gas passages so there will be no restriction to the flow of gases through the boiler to the breeching. If these areas

must be changed to suit local conditions, then the boiler manufacturer should advise the purchaser how they should be changed. The boiler manufacturer must also provide easy means for removing the soot from the boiler tubes and baffles; and he must arrange to set the boiler according to the requirements of the particular stoker in combination.

This kind of coöperation is necessary for every installation. Those installations that obtain it will have very little chance of failure.

STOKER ENGINEERING DATA

From the forgoing it will be clear that a stoker manufacturer must have certain pertinent engineering data, from the purchaser in order to study all conditions surrounding the installation. In general the following data cover a typical boiler room case and this information should be given in any specifications that are proposed covering stoker apparatus:

Name and address of Purchaser.

Location of Plant.

Stoker: (What type of stoker are you considering?)

1. Type.

Boiler:

2. Type.........Rated H.P.........Tubes high, or class, or Dia. (H.R.T.......) Tube width......tube length......
3. Centerwall dimension......
   Alleyway dimension......
   Sidewall dimension......
   Furnace dimension......
   Floor line to: Mud drum (center line) or Header, or shell (center line)

Stack:

4. No. of stacks......brick or steel......
5. Ht. above present boiler room floor.
   Inside Dia. at top.
   Boilers served......Total H.P. served......
   (each stack) (each stack)
6. Connected to boiler by: Breeching or direct.
   Stoker setting and application.
7. Old or new boiler? If old, can they be reset? Can floor be lowered?

8. What local conditions prevent the best application?
9. Will ashes be taken out: Floor or Basement? Conveyor or Car?
10. Do you contemplate installing future stokers? How many? Relation to this installation?
11. What drawings do you want for preliminary study?

Fuel to be used:

12. Name........Where mined......
13. F.C......Vol......Moist......Ash......Sulphur......
B.T.U. (as fired).

Operating service:

14. Best economy desired at........rating. What will be maximum rating? Duration (hrs.) Avg. daily rating.
15. Remarks regarding the character of service and plant organization.
16. Steam pressure of plant......Superheat......Back pressure.....

Stoker Drive: (Do you want stoker driven by)

17. Engine......
Turbine and Gear......
Motor......

Forced Draft Fan Equipment: (How many fans do you want, and how driven?)

18. Number of Fans ( )
Driven by......
( ) Turbine and Gear.
( ) Motor.
( ) Engine.

Deliveries Required:

19. Stokers and Equipment......Months.

Drawings:

20. If possible, furnish the following drawings with specification:
(1) Boilers and boiler settings as installed.
(2) Beams and columns adjacent to boilers.
(3) Details of auxiliary equipment, piping, etc., that may interfere with stoker settings.

In drawing specifications for stokers it is quite essential that they be specific and contain the engineering data required. Following is a good type of specification in general use.

SPECIFICATIONS
for
MECHANICAL STOKING EQUIPMENT
for the
PITTSBURGH ELECTRIC COMPANY
PITTSBURGH, PA.

Pittsburgh, Aug. 16, 1920.

General Data.—These specifications are intended to cover the requirements for Mechanical Stoking and Forced Draft Equipment to be constructed, delivered, and erected complete with all appurtenances and otherwise ready for service, started and put in successful operating condition by Contractor in the DuQuesne Station, located at First Avenue and Forty-Sixth Street, Pittsburgh, Pa., of the Pittsburgh Electric Company, Pittsburgh, Pa., hereinafter called the Purchaser.

Contractor may deliver his material to the station over a siding from the P. R. R., which enters the boiler room.

Boiler.—The twelve boilers under which Contractor shall erect the stokers are A. & C. Company's all wrought steel construction, arranged two in battery, each boiler containing approximately 6000 sq. ft. of water heating surface. The boilers are 21 tubes wide and 14 tubes high with 3-42″ drums, are 12′ 7″ wide inside of setting walls, are set 10 ft. high from floor line to bottom of front header and are equipped with 125° F. Atlas Superheaters.

Working Pressure.—Under normal operating conditions the boilers will deliver steam at 200 lbs. per sq. inch gauge pressure and superheated at 125° F.

Stacks.—Boilers number 2, 4, 6, 8, 10 and 12 are served by a brick stack 13′ 6″ clear diameter by 193′ above boiler room floor and located adjacent to the East side of the boiler room.

Boilers number 1, 3, 5, 7, 9 and 11 will be served by a brick lined steel stack 15′ 6″ clear diameter by 200′ above boiler room floor and located immediately over future boilers number 13 and 15.

Soot Blowers.—Each boiler will be equipped with soot blowers.

Coal.—The stoking equipment furnished hereunder shall be constructed and guaranteed by Contractor to burn successfully and economically at all rates within and including the maximum safe operating capacity of its feeding mechanism, steam coals common to the Pittsburgh market, among which the principal is Youghiougheny screenings of approximately the following analysis:

Volatile combustible matter	30.81%
Fixed carbon	56.46%
Sulphur	1.70%
Ash	11.03%
B.T.U.	13,400%

Operation.—After the first two stoking equipments are erected and ready for operation, Contractor shall furnish and shall maintain daily at the Station for a period, of six weeks, a competent firemen thoroughly experienced and skilled in the operation of the stoker equipment furnished by him. Said fireman shall direct the operation of said stoking equipment and shall carefully and thoroughly instruct Purchaser's employes in the proper care, manipulation and operation thereof, to the end that Purchaser may derive the greatest benefit from the installation.

Stoking Equipment.—Apparatus to be furnished and erected hereunder by Contractor consist of the following:

Twelve mechanical stokers of identical construction, except that six will be left hand and six will be right hand.

The necessary new lower half boiler fronts, stoker bearing bars, anchor bolts, buck stays, driving gear regulators, clean-out and inspection doors and all other appliances, attachments and apparatus necessary to make the installation complete and ready for commercial service.

Purchaser will remove lower half fronts and grates on boilers now in place and will furnish and set in place all necessary structural steel work and other foundations for carrying the stoker framework under the direction of the Contractor's erecting superintendent.

Purchaser will do all necessary cutting away and rebuilding of boiler settings and furnace brickwork.

Purchaser will provide suitable foundations and foundation bolts for forced draft equipments.

Purchaser will furnish all steam and exhaust piping outside of the stop valves and exhaust openings on Contractor's apparatus.

Purchaser will furnish and erect the air ducts and connections to the stoker wind boxes of ample area which will be arranged as indicated on drawing, attached to and forming part of these specifications.

Capacity and Efficiency.—Contractor shall state in his proposal the following:

1. The safe continuous maximum coal feeding capacity per hour of each stoker offered by him.

2. When burning Youghiougheny screenings of approximately the heating value specified above, the maximum capacity and corresponding combined efficiency each equipment will develop continuously from the boiler under which it is installed.

(a) For a period of 36 consecutive hours.

This capacity must not be less than 1200 boiler horse power.

(b) For a period of 8 consecutive hours.

(c) For a period of 2 consecutive hours.

This capacity must not be less than 1800 boiler horse power.

3. The combined efficiency when developing continuously the following capacities:

(a) 600 boiler horse power.

(b) 900 " "

4. The pounds of coal per hour or B.T.U. per hour required to be fed to stoker to maintain on a banked boiler a steam pressure of 190 lbs. per sq. inch with steam stop valve closed.

5. Time required to develop from a boiler so banked for a period of 48 hours a capacity of (a) 600 boiler horse power (b) 1200 boiler horse power.

6. Steam consumption in pounds per hour of the stokers and of the forced draft apparatus when the boilers served by it are operating at:

(a) 600 boiler horse power.

(b) 1200 " "

(c) Maximum (2-hour rate).

Mechanical Stokers.—Stokers shall be of the inclined underfeed type and shall be provided with adequate blast boxes, air openings and tuyeres for conducting the air required for combustion properly to all parts of the bed of fuel and discharging it into the bed of fuel from beneath. The blast boxes and air openings shall be so proportioned and separated into sections, each provided with suitable damper, that the air pressure in the fuel bed can be adjusted as may be required for best combustion and most satisfactory manipulation of the fire. These dampers shall be arranged to be conveniently operated from the front or side of the stokers and so provided with suitable locking device that they will remain in position when set.

Hoppers.—Each stoker shall be provided with a suitable coal hopper extending its entire width and made of sheet steel rigidly braced.

These hoppers shall be designed to receive coal from an overhead chute and deliver it to the feeding plungers. Hoppers shall have ample capacity to contain the quantity of coal required for a period of not less than 10 minutes when the stokers are feeding coal at the maximum rate.

Retort and Feeding Mechanism.—The plungers shall be arranged for receiving coal from the hoppers and delivering it to the retorts. Retorts shall be of cast-iron, of substantial construction and so designed as to be free from warping or deformation under the normal conditions of service and free from roughness or ridges which might obstruct the passage of the coal. Suitable ram blocks shall be provided in the retorts to insure even distribution of the coal. Travel of ram blocks and moving grates shall be adjustable while stokers are in operation.

Operating Shafts and Auxiliary Mechanism.—The plungers, ram blocks and moving grates shall be given a reciprocating motion by suitable rods connecting with cranks on the drive shaft. The rod ends which connect with the cranks shall be of the marine type and fitted with genuine babbitted bushings. The drive shaft shall be of cast steel with journals turned true and accurately in line. Shaft bearings shall be rigidly attached to the stoker front by suitable brackets of ample strength and free from deflection. Shaft bearing boxes

shall be genuine babbitt lined. Shaft bearings and connecting rod bearings shall be arranged for grease lubrication and grease cups shall be furnished. Power shall be transmitted to the drive shaft by a suitable cut worm and cut gear mechanism running in oil in a dust and oil tight cast-iron box having removable cover for inspection and adequate means for removing and renewing oil.

Dumping Grates.—Each stoker shall be equipped with an adequate dumping grate. Dumping grate shall be easily operated by levers suitably located in front of the boilers. Dumping grate shall be arranged to prevent the accumulation of clinkers on the bridge wall or on other parts that might choke or hinder the proper dumping of ashes, etc.

The ashes and clinkers will fall into an ash hopper located below the furnace from which they will be delivered by gravity into the ash conveying equipment for removal. The discharge openings on the ash hoppers will be about 24″ square. Adequate provision must be made by Contractor in the construction and arrangement of the dumping grates so that the clinkers discharged by his stoker when properly operated shall be small enough to discharge freely and easily from the ash hoppers in the manner described without the necessity for continual punching, raking, stirring or breaking up clinkers in the ash pit.

Smoke.—The stoking equipment furnished hereunder shall operate under all conditions of load and fuel so as to conform to the smoke ordinances of the City of Pittsburgh.

Forced Draft Equipment.—Contractor shall furnish four sets of forced draft equipment, any three of which shall be easily capable of delivering continuously a sufficient quantity of air at a sufficient pressure, including ample allowance for friction losses in air ducts, damper boxes, etc., to develop from the twelve boilers simultaneously the maximum capacity at the 2-hour rate guaranteed by him for each boiler.

The forced draft equipments shall be of similar construction and shall be driven by steam turbines of manufacture approved by the purchaser. Turbines shall operate non-condensing with normal steam pressure of 200 lbs. per sq. inch, superheated about 140° F., but they shall be designed and arranged with suitable by-pass valves hand operated, as to be easily capable

of developing the maximum capacity specified above when supplied with steam at 150 lbs. per sq. inch by gauge and superheated 100° F.

The exhaust pressure will not exceed one pound per square inch above atmospheric pressure.

Each turbine shall be equipped with safety governor adequate to prevent development of a dangerous speed, also a suitable governor to maintain a practically uniform speed under all conditions and changes of load. Speed governors shall be capable of adjustment so that there will be no interference or "bucking" when two or more fan units are operating together feeding into the main air ducts.

Contractor shall state and guarantee the maximum continuous capacity and blast pressure of each of the forced draft equipments offered by him and the speed of the equipment when operating under such maximum conditions.

Air Ducts.—Purchaser will furnish and erect the necessary air duct (a) between the fans and the main air duct and (b) between the main air duct and the blast boxes on the stokers. All air ducts will be constructed of No. 16 Birmingham wire gauge galvanized iron; joints will be substantially riveted together and soldered air tight after riveted.

Air ducts between fans and main air duct will be fitted with hand operated butterfly dampers with suitable lever handle and provided with suitable locking device that they will remain in position when set.

Air ducts between main air duct and stoker blast boxes will be fitted with butterfly dampers operated by suitable regulating devices specified below.

Driving Mechanism.—Contractor shall furnish suitable driving mechanism for stokers. Stokers shall be driven either by belt or chain from 2 line shafts furnished and erected by Contractor, one for each side of the boiler room, complete with all necessary hangers, brackets, bearings, etc.

Each stoker line shaft shall be arranged with jaw clutch between each battery of boilers and shall be driven through jaw clutches by two engines of manufacture and construction approved by the Purchaser.

Each engine shall be of ample capacity to drive all stokers

on its line shaft at maximum capacity when supplied with steam at 150 lbs. per sq. inch gauge, and exhausting against 1 lb. back-pressure by gauge, but shall be designed for normal operation at the normal operating steam pressure of the station.

Each engine shall be fitted with adequate governor arranged to operate to prevent over-speed only. Speed of the engine in normal operation shall be controlled by regulating devices specified below.

Regulating Devices.—Contractor shall furnish suitable automatic devices for regulating the supply of coal and air to the stokers in accordance with the demand for steam. The regulating devices shall be adjusted to maintain at all times such a proportion between the coal and air as will develop the highest practicable combustion efficiency and maintain the steam pressure within 2½ lbs. of the normal operating pressure at all capacities including the maximum.

It is proposed to operate the fans at constant pressure and control the air supply to the fuel bed by automatically operating the butterfly dampers in the air ducts between the main air duct and the stoker blast boxes. Contractor shall furnish for this purpose a damper regulator approved by the Purchaser, said regulator being operated directly by the change of steam pressure due to the demand for steam.

It is proposed to control the supply of fuel to the furnace by regulating the speed of the engine operating the stoker line shaft. For this purpose Contractor shall furnish suitable regulating device of type approved by the Purchaser, said regulator being operated by the steam pressure on the station, by the air pressure in the stoker blast boxes, or by such other means approved by the Purchaser as Contractor may recommend.

The regulating devices shall be of simple and substantial construction easily adjusted, arranged to maintain adjustments when once set, and connected so that they may be easily and rapidly thrown into and out of operation should it at any time be desirable to regulate by hand.

Contractor shall include in his proposal complete description of the regulating devices he proposes to use for these

purposes and show therein how change in the resistance of the fuel bed due to varying size of coal is provided for.

Description and Drawings.—Contractor shall include with his proposal a complete detailed description and completely dimensioned general arrangement drawings of the apparatus offered by him. After the contract is let Contractor shall furnish promptly complete detailed drawings of the apparatus to be furnished by him hereunder.

Tests.—At a convenient time not more than six months after completion by Contractor of his work hereunder, Purchaser will make such service and running tests as considered necessary to determine whether the equipment furnished hereunder conforms to the requirements of these specifications. Contractor shall be notified in advance of such tests and may have a representative present. Should the tests show that the equipment furnished by him does not meet the requirements of these specifications, Contractor shall promptly and at his own expense make the necessary changes to make it conform thereto.

STOKER GUARANTEES

A stoker primarily is for burning fuel and delivering the resultant heat to a boiler or other kind of vessels. How well a stoker does its work is theoretically based on the following:

(1) Pounds of coal burned per hour.
(2) Percent of combustible in ash.
(3) Percent of CO_2 in furnace gases.
(4) Percent of CO in furnace gases.
(5) Draft required in the furnace.

The purchaser however, wants to know how many pounds of steam can be obtained from a pound of coal. Consequently, stoker manufacturers are asked to make guarantees that are affected by the following:

(1) Type of boiler.
(2) Condition of brick setting.
(3) Layout and design of breeching and stack.

Stoker manufacturers therefore do not approve of making an overall guarantee, but in order to specify performances it is important that they be given all the engineering data pre-

viously asked for. For general purposes, the following performances are generally given to Purchasers:

(1) Maximum percent of rating that can be obtained from the boilers for 24 hours duration.
(2) Maximum percent of rating that can be obtained from the boilers for short duration—to carry over peaks.
(3) Combined boiler and grate efficiency at the boiler rating that boilers will be operated at the greatest number of hours during the day.

TYPICAL STOKER CONTRACT FORMS

Most stoker manufacturers sell their product on a proposal form, which is submitted to the purchaser and if accepted by him and approved by the manufacturer becomes a contract. The typical form used is as follows:

THE IDEAL STOKER COMPANY.

CONTRACT PROPOSAL No.........Detroit, Mich.,............192..

To ....

Hereinafter called the Purchaser.

P. O. Address..

Shipping Address ....

For Stoker equipment for use in connection with the following:
(A rated boiler horse power being taken as 10 sq. ft. of effective water-heating surface) ....

....

(1) THE IDEAL STOKER COMPANY (hereinafter called the contractor) proposes to furnish the Purchaser, f.o.b. cars point of shipment, apparatus as specified below:
(*a*) Stokers:
(*b*) Actuation:
(*c*) Stoker companies arrange *A, B, C,* etc., for their individual equip-
(*d*) ment requirements.
(*e*)
(*f*)
(*g*)

(2) FURNISHED BY THE PURCHASER:

The Purchaser agrees to unload all mechanical stoker equipment and accessories herein specified to be furnished by the contractor, and to place same adjacent to the foundations upon which the said equipment and accessories are to be erected. All materials, boxed or otherwise, are to be protected from the weather.

The Purchaser will furnish labor and tackle for erecting all equipment.

The Purchaser will furnish, in place, all foundations, anchorage and anchor bolts; steel and concrete pits, air duct, ash-pit doors, supports for line shaft hangers, boilers and boiler-setting walls, draft gauges, all steam piping, electric wiring, and all other equipment not otherwise specified herein.

(3) SUPERINTENDENCE:

Unless otherwise stipulated, all materials shall be installed by and at the expense of the purchaser and under the supervision and direction of a Superintendent, to be furnished by the Contractor, for whose services the Purchaser agrees to pay the Contractor the sum of.................. ($......) dollars per calendar day (which shall include time traveling) plus living and traveling expenses, all of which shall be paid by the Purchaser as invoices are presented; it being understood and agreed that during the term of such services, the Superintendent shall be the Purchaser's employee.

(4) PERFORMANCE CONDITIONS:

It is understood and agreed that any guarantees are based upon the Purchaser providing the following conditions:

(*a*) That the stoker equipment has been erected in accordance with the Company's plans and specifications, and is properly operated.

(*b*) That the boilers shall be of......type with a minimum distance from heating surface of boiler to grate of......ft.

(*c*) That the boilers are in good condition and heating surface clean, inside and out.

(*d*) That the baffling is tight and so arranged that the temperature of the flue gases at boiler outlet shall not exceed 550 degrees F. when the boiler is operated at 150% of nominal rating.

(*e*) That the boiler setting and furnace brickwork are in first-class condition and free from excessive air leaks, as determined by candle flame, in accordance with A. S. M. E. Boiler Test Code.

(*f*) That the draft (negative pressure) provided by the Purchaser and available in the furnace of each stoker, shall not be less than......inches water column when boiler is operating at maximum rating specified.

(*g*) There shall be available for each stoker, when boiler is operating at maximum rating specified, not less than......cubic feet of air per minute referred to......barometer, and 70 degrees Fahr. at......inches water column static pressure at stoker forced-draft inlet.

(*h*) That............fuel, known commercially as......size......and of the following proximate analysis shall be used:

..........% Fixed Carbon
..........% Volatile Matter
..........% Ash
..........% Moisture
..........% Sulphur (Sep. Det.)

B.T.U. per pound as fired not less than......
Fusing temperature of ash not less than......Fahr.

(5) DATE OF SHIPMENT:

The Contractor agrees (unless delayed by the Purchaser) that shipments will be made......................days after acceptance of this proposal.

The Purchaser shall furnish the Contractor, within ten days from date of acceptance of this proposal, all data necessary to enable the Contractor to complete his drawings. The Contractor shall be privileged to extend date of shipment specified without notice, in case the Purchaser delays furnishing information necessary to complete the Contractor's drawings, or delays in approving same. The Contractor shall be granted reasonable time after final drawings are approved to complete material lists and arrange for shipment. The acceptance, when delivered, of the mechanical stoker equipment herein specified to be supplied by Contractor, shall constitute a waiver of all claims for damages caused by any delay.

(6) CONSEQUENTIAL DAMAGE:

The Contractor shall not be held liable for any loss, damage, detention or delay caused by fires, strike, civil or military authority, or by insurrection or riot, or by any other cause which is unavoidable or beyond its reasonable control, or, in any event, for consequential damages.

(7) REPLACEMENT OF DEFECTIVE PARTS:

The Contractor agrees to correct, and shall have the right to correct, by supplying new parts at its own expense, f.o.b. Point of Shipment, any defects in the apparatus furnished by the Contractor which may develop under normal and proper use, within one year from the shipment thereof provided the Purchaser gives the Contractor immediate written notice of such defects, and correction of such defect, by supplying such parts by the Contractor, shall constitute a fulfillment of all his obligations to the Purchaser hereunder.

Acceptance by Purchaser

The foregoing proposal is hereby accepted and agreed to this.....day of.........................192....

....
(Purchaser to sign here)

By............................

IDEAL STOKER COMPANY

By............................

Approved at...................

This.....day of............192...

IDEAL STOKER COMPANY?

By............................

SPECIFICATIONS FORMS

Every stoker builder has certain specifications for the particular type of stoker sold, but in general these forms cover about the same items as follows:

CHAIN GRATE STOKERS

The following items are named in that part of the proposal covering materials required.

1. General description of stoker.
2. Equipment furnished by Contractor.
   (1) Number and size of stokers.
   (Sq. Ft. grate surface and weight within 5%)
   (2) Number and size of ignition arches.
   (3) Number and size of upper arches.
   (4) Type of water backs.
   (5) Inspection doors.
   (6) Rails.
   (7) Ledge Plates.
   (8) Arch cover Plates.
3. Stoker drive furnished by:
   (1) Number, size, types of prime movers, pulleys, shafts, hangers and boxes.
4. Forced draft furnished by:
   (1) Description and method of operation.
   (2) Regulation.
5. Purchaser will furnish.
   (1) All masonry, foundations, grouting foundation, bolts and supporting structure.
   (2) All labor for unloading and erection of stoker equipment.
   (3) All ash pits and ash pit construction.
   (4) Complement of gauges, for draft, air pressure, etc.
   (5) All piping, valves, wiring and other connections.
6. Optional Equipment.
   (1) Curtain wall supports furnished by purchaser or contractor.
   (2) Lower boiler fronts furnished by purchaser or contractor.
   (3) Drip pans for header furnished by purchaser or contractor.
7. Boilers.
   (1) Number and type.
   (2) Horse power.
   (3) Sq. Ft. heating surface.
   (4) Width and length furnace.
   (5) Setting height, single or battery setting.
   (6) Steam pressure and superheat.

BOILER ROOM LOG

I. Installation Data:

1. Plan of Boiler room.
2. Setting Details.
3. Breeching Details.
4. Stack Details.
5. Coal handling Machinery Capacities.
6. Ash handling Machinery Capacities.
7. Oil burning equipment details.
8. Stoker details.
9. Piping details.
10. Heater details.

II. Labor Data—Boiler Room:

	Numbers	Hrs.	Rates	Schedules	Field.
1. Engineers	Numbers	Hrs.	Rates	Schedules	Field.
2. Firemen	"	"	"	"	"
3. Water Tenders	"	"	"	"	"
4. Coal Passers	"	"	"	"	"
5. Ash Handlers	"	"	"	"	"
6. Boiler Washers	"	"	"	"	"
7. Janitors	"	"	"	"	"
8. Specialists	"	"	"	"	"
9. Apprentices	"	"	"	"	"

10. Chart showing responsibility and authority. Sec. III. 10.

III. Labor Data—Engine Room:

	Numbers	Hrs.	Rates	Schedules	Field.
1. Engineers	Numbers	Hrs.	Rates	Schedules	Field.
2. Oilers	"	"	"	"	"
3. Electricians	"	"	"	"	"
4. Janitors	"	"	"	"	"
5. Repair men	"	"	"	"	"
6. Apprentices	"	"	"	"	"
7.					
8.					
9.					

10. Chart showing responsibility and authority. Sec. II, 10.

IV. Maintenance Data—Boiler Room—One Year:

1. Brickwork	Men—Hrs.	Rates	Materials		
2. Boiler Tubes	"	"	"	(individual	Boilers)
3. Boiler Trimmings	"	"	"	"	"
4. Auxiliaries	"	"	"	"	"
5. Stokers	"	"	"	"	"
6. Oil Equipment	"	"	"	"	"
7. Feed Water Heaters	"	"	"	"	"
8. Ash Handling	"	"	"	"	"
9. Coal Handling	"	"	"	"	"
10. Building Repairs	"	"	"	"	"

V. Coal Data:

1. Quantities by days, months, year. Curve.
2. Daily consumption curve by hrs. Add VI 2 on heat equiv.
3. Heat values per lb.
4. Proximate analyses.
5. Rate of combustion per sq. ft. per hr. Max.-Min. Sec. VII, 6, 7, 8.

VI. Oil Data:

1. Quantities by days, months, year. Curve.
2. Daily consumption curve by hours. Add V 2 on heat equiv.
3. Heat values per lb.
4. Proximate or Ultimate analyses.
5. Rate of combustion combine with V 5 on heat equiv. basis in curves.

VII. Boilers in Service

1. Total number in service daily—Chart for mo. Averages per yr.
2. Maximum capacity (B.H.P.) per boiler unit.
3. Minimum capacity (B.H.P.) per boiler unit.
4. Number units operating max. cap. on peak load.
5. Number units operating min. cap. on valley load.
6. Total max. B.H.P. developed at peak load—Rate of combustion. Sec. VII 8.
7. Total min. B.H.P. developed at valley load—Rate of combustion. Sec. VII 8.
8. Total grate area in service daily—Chart per mo. Avgs. per yr.
9. Time in hours to get up steam from cold boiler.
10. Description of banked fire.
11. When and how is oil used.

VIII. Electrical Output Data:

1. Characteristic Load (K.W.H.) Curves—Daily.
2. Characteristic Load (K.W.H.) Curves—Monthly.

IX. Water Data:

1. Purification System and Methods—Raw Water Analyses.
2. Meter Monthly Readings—Daily—Monthly Charts.
3. Steam charts—Daily—Monthly.

X. Temperature Data—Boiler Room:

1. Feed Water.
2. Furnace.
3. Uptake.
4. Before and after economizer—Gas side.
5. Before and after economizer—Water side.
6. Superheat—actual and increase.
7. Stack Base.
8. Boiler Settings—Charts.
9. Boiler Room.
10. Breeching at various points.

XI. **Pressure Data:**
1. Steam at Boiler—charts.
2. Fall through superheaters.
3. Fall to engines.
4. Draft.
   a. Stack Base.
   b. Breeching at various points.
   c. Boiler Setting throughout—chart. To be studied in conjunction with X 2, 3, 10.
   d. Between interior and exterior boiler rooms.
   e. Source of air supply.
5. Oil Equip.
   a. Steam pressure at burner.
   b. Oil presure at burner.

XII. Flue Gas Data:
1. Continuous C.O. charts.
2. Flue Gas analyses at uptakes.
3. Flue Gas throughout setting simultaneous with XII, 2.
4. Determinations of air leakages based on XII, 3.

XIII. Routine Service—Boiler Room:
1. Soot blowing, Manner, Time, Duration, By Whom—Effectiveness.
2. Soot deposits.
   a. Frequency of removal.
   b. Quantity of removal.
   c. Inspected by whom.
3. Boiler Washing.
   a. Schedule.
   b. Time taken for each boiler unit.
   c. Method.
   d. By whom inspected.
4. Setting Overhauling.
   a. Air leakage tests.
   b. Baffle leakage tests.
   c. Boiler covering.
   d. Inspected by whom.
5. Blow Downs.
   a. Frequency—Time of Day—By Whom.
   b. Duration.

XIV. Smoke Data:
1. Continuous records.
2. Method used in judging smoke density.
3. Causes of smoke production.
4. Meaning of periods when smoke is absent—Sec. XII, 2.
5. Time when most prevalent.

XV.

1. Heat value chart showing total supply daily for 30 days.
2. Heat value chart showing total supply monthly for 12 months.
3. Heat absorption showing total supply daily for 30 days.
4. Heat absorption showing total supply monthly for 12 months.
5. Heat chart by several furnaces factors shown graphically.
6. Heat chart by several boiler setting factors shown graphically.
7. Heat chart by several breeching and stack factors shown graphically.
8. Heat reclaimed from exhaust shown graphically.
9. Heat delivered to engines after subtracting B.R. auxiliaries.
10. Heat delivered to switch board as electric energy.
11.
12. Chart showing combination of all above month by month.

XVI. Cost of Power Production on K.W.H. basis:

1. Coal
2. B.R. Labor.
3. B.R. Maintenance.
4. Engine Room Labor.
5. Engine Room Maintenance.
6.
7.
8.
9. Chart combining all XVI items month by month.

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